Effects of Nanoparticles on the Environment and Outdoor Workplaces

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Abstract:
Today, most parts of different nanotechnologies are growing and developing without any special rules and regulations. This could result in undesirable changes in the environment and affect workers in indoor and outdoor workplaces. Carbon-based nanoparticles, such as fullerenes, nanotubes, the oxides of metals such as iron and titanium, and natural inorganic compounds, including asbestos and quartz, can have biological effects on the environment and human health. The risk assessment of such nanoparticles requires evaluation of their mobility, reactivity, environmental toxicity, and stability. With the increasing use of nanoparticles for commercial and industrial purposes, the debate becomes whether the numerous benefits of nanoparticles can overcome the economic costs, environmental impacts, and unknown risks resulting from their use. To date, few studies have been conducted on the toxic and environmental effects that result from direct and indirect exposure to nanoparticles, and there are no clear standards to determine their effects. Lack of technical information in this regard has provided an appropriate context for supporters and opponents of nanoparticles to present contradictory and ill-considered results. Such an uncertain atmosphere has caused increased concerns about the effects of nanoparticles. Therefore, adequate studies to determine the exact, real risks of the use of nanoparticles are required. The information resulting from these studies can be useful in minimizing the environmental hazards that could arise from the use of nanoparticles. Thus, this paper briefly explains the classification of environmental nanoparticles and how to deal with their formation, diffusion, environmental fate and impacts, and our exposure to them.

Keywords: Nanotechnology; Nanoparticles; Environmental impacts

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1. Introduction

Nanoparticles have existed for millions of years on the Earth, and they have been used by humans for thousands of years. In recent years, due to the increased human capacity to make synthetic nanoparticles, much attention has been focused on this type of material. Today, nanoparticles are used in different areas, such as the electronics industry, medical applications, pharmaceuticals, cosmetics, and environmental processes. Due to the significant potential of this technology, investments in the applications of nanotechnology are a growing trend worldwide (1).

The available information on the current uses and the production rate of nanoparticles is inadequate. According to estimates of the production rate of nanoparticles, about 2,000 tons were produced in 2004, and it is expected that the production rate will increase to 58,000 tons by 2020. Due to the exponential increase in the production and use of nanoparticles, environmental and human exposures also will increase. As a result, their potential for causing dangerous effects has become a matter of concern for some researchers (2). In this paper, we discuss the behavior of nanoparticles in the environment and compare industrial nanoparticles, the unintentional production of nanoparticles, natural nanoparticles, and the environmental effects of nanoparticles.

2. Definition, Classification and Applications of Nanoparticles

Nanotechnology is defined as the science of identification and control of materials with approximate dimensions of 1 to 100 nm that are used in new technologies due to their unique physical properties (3). Thus, nanoparticles are materials that are less than 100 nm in size. These particles may be spherical, tubular, or irregularly shaped. Nanoparticles are classified into two groups of natural and synthetic nanoparticles, and these two groups are divided further into organic and inorganic (mineral) subgroups based on the chemical compositions of the nanoparticles. Fullerenes and carbon nanotubes (CNTs) with geogenic or pyrogenic origin are among the natural nanoparticles. Synthetic nanoparticles may be produced either inadvertently (due to combustion or as a by-product) or deliberately. Nanoparticles that are produced deliberately using specific processes are called engineered or manufactured nanoparticles, e.g., fullerenes and CNTs. With regard to environmental issues, the current research related to nanotechnology is focused mainly on engineered nanoparticles (4).

2.1. Organic Colloids

The colloidal materials in natural waters include particles and macromolecules that range in size from 1 nm to 1 μm. Thus, some of these particles are nanoparticles. Although human knowledge concerning the structure and environmental impacts of natural colloids has increased significantly in recent years, their exact composition and functions are still unclear (5).

2.2. Soot

The processes of natural and artificial combustion that occur in mobile or fixed sources emit particles with a wide range of sizes. Of such particles, only the very tiny particles, i.e., the so-called 'ultra-fine' particles are small enough to be classified as nanoparticles. In this paper, all the carbon black particles in the range of nanoparticles are specified by the term "soot." Soot is released into the atmosphere due to the incomplete combustion of fossil fuels and renewable fuels, and it gets into water and soil via the precipitation that occurs. Carbon black, the industrial form of soot, has various uses, e.g., as a filler in rubber compounds, especially in tires. Particles of carbon black are in the nanometer size range, and their mean sizes in different materials vary from 20 to 300 nm (6).

2.3. Natural and unintentionally-produced fullerenes and carbon nanotubes

Although fullerenes and carbon nanotubes are considered to be engineered nanoparticles, natural fullerenes and carbon nanotubes also exist in the environment. Some of these fullerenes have an interstellar origin and were brought to the Earth by comets and meteorites (7).

2.4. Natural and unintentionally-produced inorganic Nanoparticles (NP)

Natural mineral or inorganic nanoparticles can have atmospheric, geological, or biological origins. Mineral nanoparticles exist everywhere in the soil and in geological systems. Aerosols that are present in the atmosphere also are considered to be nanoparticles, and they are the precursors of the larger particles that strongly influence the global climate, atmospheric chemistry, the visual field, and global emissions of pollutants. Some of the randomly and unintentionally produced nanoparticles are the platinum and radium particles that are produced in the catalytic converters of cars. Although most of these platinum and radium particles are attached to larger particles, about 17% of them are found among the fine aerosols (diameters less than 0.43 μm) (8).

2.5. Engineered fullerenes and CNTs

Among the fullerenes, buckminsterfullerene (C60) has been studied more extensively than the others, likely because it was the earliest known member of the fullerene family. Most fullerenes are used in polymeric composites, such as thin membranes, and in electro-optical devices and biological applications. Due to the poor solubility of fullerenes in water, much research has been done in order to enhance their usefulness, and numerous compounds have been made from C60, each of which has its own characteristics and attributes. Carbon nanotubes (CNTs) have become an ongoing and controversial topic in physics (9). Depending on the synthesis method and the techniques used to isolate and remove unconventional byproducts, various types of carbon nanotubes with different characteristics have been obtained (10).

2.6. Engineered polymeric NP

Synthetic nanoparticles resulting from organic polymers have been used in many applications in medicine as drug-delivery devices. Different types of these nanoparticles have been studied regarding their ability to pass through brain-blood barriers. Many polymeric nanoparticles also have been produced to improve soil and underground water (11).

2.7. Engineered inorganic NP

Engineered inorganic nanoparticles include a wide range of materials, such as elemental metals, metal oxides, and metal salts. Elemental silver is used as a bactericide in many products. Elemental gold is used in various applications due to its catalytic nature. Several studies of the application of nanotechnology in the environmental context have been conducted regarding the use of nanoscale, zero-valent iron (nZVI) to modify and improve underground water (12).

3. Effects of nanoparticles on organisms

3.1. Absorption and toxicity

Nanoparticles can pass through different cell membranes of mammalians and be absorbed in them, and their absorption rates depend on their size (11). Then size of the nanoparticles and their distribution, aggregation, and sedimentation in the cells are the most important parameters in determining their absorption rates. In some particular cells, the cellular absorption of nanoparticles occurs by endocytosis or phagocytosis. The nanoparticles are stored in some specific places in the cells, such as the mitochondria, and they can cause toxic reactions. The toxicity of nanoparticles is related to their small size, large surface area, and their ability to produce reactive oxygen species (13). Nanoparticles can cause inflammation and fibrosis in multicellular organisms, and their main impact in unicellular organisms is their anti-oxidant property and cytotoxicity (14).

Several respiratory and cardiovascular diseases are caused by carbon black particles in humans. Most carcinogenic materials, such as polycyclic aromatic hydrocarbons (PAHs) and very tiny soot, can find their way deep into the lungs and cause toxic effects. Diseases associated with air pollution due to nanoparticles can cause premature deaths of workers in the gas, coal, and asphalt industries as well as in workers in plants that produce carbon electrodes (15).

3.2. Absorption under environmental conditions

Most toxicology studies of nanoparticles have been performed on mammalian cells. In these studies, the nanoparticles were exposed to cell culture media that contained protein and other biological compounds. The cellular surfaces of prokaryotes, such as bacteria, provide a protective barrier that inhibits the absorption of many types of nanoparticles, since no mechanism exists for them to transfer colloidal particles through the cell wall. However, the situation is different in eukaryotes, such as early, unicellular organisms and multicellular organisms, since they do have some mechanisms for the entry of nanoparticles and microparticles, i.e., endocytosis and phagocytosis. The absorption of different nanoparticles by cells has been observed, e.g., carbon nanotubes can be absorbed by protozoa and accumulate in the cells' mitochondria (16).

Latex nanoparticles are absorbed in the body and eggs of Oryziaslatipes, a small Japanese fish, and accumulate in the gills, intestines, brain, genital organs, liver, and blood. Inorganic nanoparticles also are absorbed by the cells, e.g., zinc oxide can enter bacteria. CeO_2nanoparticles can be absorbed by the cell wall of E. coli bacteria (17).Toxicological studies have shown that nanoparticles have toxic effects on unicellular aquatic organisms and aquatic animals, such as fish and Daphnia (16). Carbon nanotubes are a limiting factor of growth in protists, and they have toxic effects on the respiratory systems of rainbow trout. Yet, in a medium containing yeast, carbon nanotubes stimulated the growth of some unicellular protists. Carbon nanotubes and all of their byproducts increased mortality in some fresh water crab species (18). Carbon nanotubes coated with fat are simply absorbed by Daphnia and can produce acute toxic effects at high concentrations (19). Fullerenes have very little impact on the performance or structure of the microbial population in the soil or their respiration and enzymatic activity. The cell walls of bacteria have adapted physiologically to the presence of fullerenes (20).

There is a significant amount of information about using silver nanoparticles as a bactericide. The silver nanoparticles damage the cells of the bacteria, and they die (21).The interaction of the nanoparticles with the cells depends on the size of nanoparticles (22), and it also appears to be dependent on the shape of the particles. Apparently, silver nanoparticles are far more toxic to E. coli than silver ions (23). Inorganic nanoparticles of titanium dioxide, sulfur dioxide, and zinc oxide have toxic effects on bacteria, and their toxicities are increased in the presence of light. Although large masses of titanium dioxide have no harmful effects on the health of aquatic organisms, titanium dioxide nanoparticles do have harmful effects (24).

3.3. Nanoparticles in outdoor spaces

Many natural and manmade processes lead to the release of nanoparticles in indoor and outdoor spaces. Some construction workers, gas and petroleum transmission pipeline workers, members of police forces, farmers, and workers in many other jobs spend their work time in outdoor environments. Few studies have been conducted on the effects of the exposure of such workers to nanoparticles; however, the limited research that is available suggests that such people are subject to increased risk of adverse health effects caused by their exposure to nanoparticles. In some cases, the penetration of nanoparticles from indoor places into the outdoor environment is likely. For example, the nanoparticles that pass through a filtration system can enter the outdoor spaces through ventilation ducts and affect the workers outside. Due to their special physical and chemical properties, nanoparticles readily enter indoor and outdoor workplaces and are distributed throughout these spaces. They can cause biochemical damage by creating some reactions in the cells of the human body. Today, many researchers are measuring the concentrations of various nanoparticles in indoor and outdoor workplaces in order to determine the workers' levels of exposure.

Extensive research is needed to assess the reactions of nanoparticles with biological systems. Also, studies should be considered to determine the absorption pathways for nanoparticles, the mechanisms by which they interact with cells, their bio-distribution, and their excretion pathways in the human body (25-27). Recently, some researchers have conducted some studies on measuring nanoparticles in different environments, and they have monitored these compounds in indoor and outdoor work environments. They have developed approaches and devices for the measurement of the concentrations of nanoparticles that aid in monitoring workers' exposures in a variety of work environments (28).

3.4. Interaction of NPs with plants

In a study of the impact of aluminum oxide nanoparticles on the growth of plants' roots, a slight reduction was seen in the growth of roots in the presence of uncoated alumina nanoparticles, but no reduction was observed when the nanoparticles were coated with phenanthrene. The surface properties of alumina have an important role in its toxicity (29). Several papers have shown that a positive effect on the growth of spinach occurred when the spinach seeds were smeared with titanium dioxide nanoparticles or the leaves were sprayed with these nanoparticles. Titanium dioxide nanoparticles, unlike larger samples of titanium dioxide, can enhance enzymatic activity, increase the absorption of nitrates, and accelerate the conversion of inorganic nitrogen to organic nitrogen. There is some limited information that suggests that nanoparticles of inorganic oxides can interact with plants' cells and with green algae that have cell walls similar to those of other plants (30).

Nanoparticles can interact with plants' roots by being absorbed from the surface of the roots, entering the cell wall, and being absorbed into the roots' cells. It also is possible that nanoparticles enter the intercellular space where they can be absorbed by the membranes. The surfaces of plants' cells have a negative charge, which allows the entry of negatively-charged species into the intercellular space of the roots' bark. Nanoparticles can find their way into the woody tissue of the plant by entering this space (31).

3.5. Interactions among organisms, NPs, and contaminants

The interaction of nanoparticles with toxic material and organic compounds can either increase or reduce their toxicity. Thus, even though nanoparticles can have harmful environmental effects, they also can be helpful for the environment. The contaminants may be absorbed by nanoparticles, thereby reducing the concentrations of the free molecules of pollutants around the cells and reducing the toxic effects of the pollutants. However, if the nanoparticle and its combination with the pollutant would not be toxic, no toxic effects may be seen (4).

4. Environmental risk assessment of NPs

The environmental impacts of nanoparticles depend on how they are used in the workplace, how they are separated into different media (e.g., water and air), their mobility in each of these media, and their stability. Such basic information about the behavior and toxicity of nanoparticles is required to assess their risks; however, a realistic assessment cannot be done based exclusively on this information; rather, some data on the expected concentration of nanoparticles in environmental systems would be necessary, and, to date, there is no accurate concerning such concentrations. As a starting point for the environmental risk assessment of nanoparticles, the resources, environmental pathways, and applications of nanoparticles, as well as the plants and animals that are sensitive to nanoparticles, must be identified (32).

5. Conclusion

In recent years, rapid advances in nanotechnology have brought major developments in the areas of the environment, medicine, agriculture, industry, and other sciences. The nanoparticle technology has made an important contribution to the field and provided a basis for the development of nanotechnologies. Despite the fact that the major effect of particle size on materials' toxicities has been specified in the past, the effect of particle size on the behavior and reactivity of nanoparticles remains unclear. New issues and ideas about nanoparticles require the development of appropriate laboratory methods. Currently, there are several uses of nanoparticles in the environment, including the removal of contaminants from water, sewage, and air. Also, they have been used in environmental instruments, such as sensors, green nanotechnology, and the reduction of greenhouse gases. However, apart from the usefulness of nanoparticles, they can cause some hazards for the environment from their production to their disposal.

As a result, environmental risk assessments of nanoparticles during their lifecycles are essential. It is worth noting that the study of the effects of nanoparticles on industrial and non-industrial workplaces also is very important. Also, the measurement of exposures of workers in outdoor workplaces to nanoparticles released from various sources is essential. It is recommended that additional information be gathered on the characteristics of various nanoparticles, especially their toxicological properties, and placed in databases that can be made readily available to researchers. In plants that deal with engineered nanoparticles, safety measures should be considered to minimize occupational exposure. Also, some guidelines should be established concerning the safe handling and use of nanoparticles in research laboratories. Finally, while promoting the benefits of the use of nanoparticles in various fields, we should ensure that no adverse effects result from their use.

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Conflict of Interest:

There is no conflict of interest to be declared.

Authors' contributions:

All of authors contributed to this project and article equally. All authors read and approved the final manuscript.

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