Chapter 22

Impact Of Nano-biomaterials On the World

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Table Of Contents

Abstract

People have been exposed to airborne nanosized materials (100 nm) for thousands of years, but since the industrial revolution, particularly with regard to combustion operations, the level of exposure has significantly increased. Since the advent of nanotechnology two decades ago, the danger of exposure to nanomaterials by ingestion, absorption through the skin, absorption through the dermis, and medication administration utilizing designed nanoparticles has grown. Nanomaterials acquire new mechanical, electrical, optical, catalytic, and, last but not least, biological capabilities when they shrink from bulk to nanoscale. The creation, usage, and disposal of the product, as well as the toxicological impacts of nanomaterials, must all be studied. Basic multidisciplinary research including materials scientists, toxicologists, medical professionals, and environmental engineers is necessary to better understand the health risks and safety concerns of nanoparticles.

Keywords: Nanomaterials, Health Hazards, Cytotoxicity, Human health, Environment

22. Introduction

Nanotechnology which combines engineering with biology, chemistry, medicine, and physics, is seen by many experts as the next logical step in science.[1] A substance's physical and chemical characteristics can alter significantly from those of the same material in bulk form when its dimensions are reduced to extremely tiny levels. The development of microscopic or even molecular devices using current nanotechnology has the potential to advance energy, space exploration, medicine, and environmental protection[2]. It won't be long until the entire history can be compressed inside our pockets or the system extended by specially created molecules that resemble life systems, thanks to our rapidly expanding knowledge of nanoscience and our capacity to engineer new goods and services. Engineered nanomaterials, such as those used in cosmetics, food packaging, medication delivery systems, therapies, biosensors, and other products, are quickly encroaching our daily lives.[3, 4] Nanomaterials are widely employed for a variety of commercial products such as wound treatment, detergents, or antimicrobial coatings because their size scale is close to that of biological macromolecules and they have antibacterial and odor-fighting characteristics.[5, 6]

As the use of nanomaterials is growing, so does the population that is exposed to them. Despite the clear advantages of using nanoscale materials, there are unanswered questions regarding the potential effects of nanoparticles on the environment. Before mass production of nanomaterials, one of the most important problems that must be resolved in the near future is how harmful they are to people and how they affect the environment[7]. There is much discussion about the possibility that the unique features of nanoparticles could have hazardous biological impacts. What biological reactions might be expected when nanoparticles undergo biodegradation in the cellular environment? For instance, biodegraded nanoparticles may gather inside cells and cause intracellular changes including organelle integrity disruption or gene alterations. One of the most pressing questions is whether nanomaterials are more dangerous than their non-nano counterparts. In the environment, can nanoparticles degrade into more dangerous forms? It is critical for nanotoxicology research to uncover and comprehend how nanomaterials affect the environment before they can be used in daily activities in order to avoid their negative effects.[8] This chapter states recent developments in nanomaterial toxicity and environmental impact to answer concerns about potential environmental implications of upcoming nanotechnologies.

"While it is still a young field of study, nanotechnology has the potential to have a big impact on how we approach and solve problems. It is believed that nanotechnology would significantly affect research, food systems, agriculture, medicine, and the environment".

22.1 Knowledge Gaps In Fate, Exposure And Toxicity Of Nanomaterials

The National Institute for Workplace Safety and Health (NIOSH) is the principal government organization conducting research on the potential effects of nanomaterials on occupational safety and health. Whereas; in India National Institute Of Occupational Health (NIOH) is established to prevent and control occupation related Health problems by creating a safer work environment through intensive research (basic/epidemiological/translational), development of appropriate technology for risk minimization. In this role, NIOSH is aware that the research community is at the forefront of developing new nanomaterials, evaluating their use in various contexts, and figuring out their toxicological and environmental effects. Despite the lack of widespread knowledge of the threats that nanoparticles pose to human health and the environment, it is advisable to be aware of the most recent information and handling guidelines for nanomaterials from NIOSH and other reliable sources. Although the causes of nanotoxicity are not fully understood, it is known that nanoparticles have hazardous effects on the lungs, reproductive system, heart, gastrointestinal tract, skin, and immune system.[9] Nanomaterials can also result in persistent contamination of the air, water, and—most importantly—soil.[10,11] The uptake of nanomaterials by plants, their transportation in the environment, and indicators of ecological exposure can all be significantly impacted by changes to the fundamental features of nanomaterials (such as size, shape, oxidation state, and partitioning). Because these pollutants are too small to be easily detected, they have long-term impacts that are unknown. Before large-scale nanotechnology is fully established, larger and multicenter investigations are required to ascertain human reaction and the destiny of the nanoparticles in the environment.[12]

We don't know enough about how prolonged, low-dose exposure to nanomaterials can damage human health. The lungs, gut, and skin are the three main organs via which humans are exposed. In addition to being used in food goods and packaging, nanomaterials may be ingested or inhaled by factory workers. Nanomaterials become lodged in the liver after entering the body, but the long-term risks they bring are unknown. The issues that can arise from new breakthroughs have already been seen in the world. It is crucial that advancements in nanotechnology do not lead to similar health crises given the world's experiences with asbestos (which, despite being used for thousands of years, was only discovered as a source of disease in the 1900s), the contentious development of genetically modified foods, and the highly relevant microplastics crisis. We can protect users, workers, and the surroundings from potential health and safety dangers by strengthening non-animal tests for nanotechnology. Our lives have already been improved by nanotechnology, and with a better understanding of their safety, we may more confidently take use of the advantages this new technology brings.

22.2 Impact of Nanomaterials On Human Health

The possible effects of employing nanotechnological components and tools on human health are known as the health repercussions of nanotechnology. There is a lot of discussion over whether or not nanotechnology will be good or bad for human health because it is a relatively young science. The potential medical uses of nanotechnological advancements to treat disease and the possible health risks provided by nanomaterial exposure make up the two areas of the health effects of nanotechnology. Researchers, engineers, and medical experts are using a highly developed set of nanoscience and nanotechnology methodologies to study the present worldwide epidemic and how it may possibly help the scientific, technological, and medical sectors combat the pandemic.[13]

The majority of naturally occurring substances and chemicals that come into touch with the human body have created tolerance. It is less likely to be safe with novel drugs since it lacks natural tolerance to them. Skin, lungs, and the digestive system are three ways that nanoparticles might enter the body. The development of "free radicals," which can harm cells, may be facilitated by this. Concerns have also been raised about nanoparticles' potential to enter the circulation and pass across the blood-brain barrier. According to Kirchner et al.[14], there are three main reasons why nanoparticles become harmful when they come into touch with live cells:

"(i) Chemical toxicity of the materials used to make them. Cd2+, for example, is released from cadmium selenide nanoparticles.

(ii) Nanoparticles' small size allows them to adhere to cellular membranes and enter cells. Attachment of nanoparticles to membranes and storage of nanoparticles within cells can impair cellular functions, even if the nanoparticles are chemically inert and do not decompose or react with other matrix components.

(iii) Form. Carbon nanotubes, for example, can easily pierce cell membranes."

The environmental effects of nanotechnology are becoming a more active area of study. Until recently, the potential negative effects of nanomaterials on human health and the environment were speculative and unsubstantiated.[15, 16] Wiesner et al.[17] examined the risks of manufactured nanomaterials as well as potential human and animal health risks. They found that fullerene-based nanomaterials are cytotoxic to human cells, may damage DNA, accumulate in rat livers, and create reactive oxygen species in addition to having antibacterial capabilities. Although the Federal Drug Administration (FDA) in the USA has approved some non-toxic nanoparticles for use in paints and sunscreen lotions, there are toxic nanoparticles and chemicals that are known to accumulate in the food chain, such as asbestos, diesel particulate matter, ultra-fine particles, and lead. It is well acknowledged that it is extremely difficult to apply knowledge of bulk materials to nanoparticles because of how different their chemical characteristics are from those of bulk materials.

Anti-bacterial silver nanoparticles dissolve in acids that would not dissolve bulk silver, which is one sign of their higher reactivity.[18] A list of some exposure episodes involving people and the environment is shown in Table 2. The table unequivocally demonstrates that nanoparticles may be released from both point sources and non-point sources, such as businesses, landfills, moist deposition from the atmosphere, storm-water runoff, and attrition from products containing nanomaterials. In the atmosphere, nanomaterials are subject to photochemical reactions. Within living organisms, they can accumulate, alter, or decay. Nanomaterials must be removed from the air using air filters and respirators due to diverse atmospheric transmission processes. Inhaling nanomaterials that are released into the air and eating drinking water or food (like fish) that has collected nanoparticles are alternative exposure situations. Manufacturing is the most frequent moment when humans come into contact with nanomaterials.

Dermal exposure via sunscreen and cosmetics is also possible. To make the particles mobile in the subsurface and efficiently transfer nano iron to cells, special surface coatings will be required. These changes may increase their risk of inadvertent exposure to people and other creatures. Many other types of nanomaterials (such metal-oxide nanoparticles and quantum dots used as contrast agents in magnetic resonance imaging) will also require surface coatings in order to perform their intended function. Despite the fact that there are many different types of nanomaterials, free nanoparticles have mostly been the subject of concerns.[19] The likely pathways through which nanoparticles enter and move throughout the human body are depicted in Fig 22(a).[20]

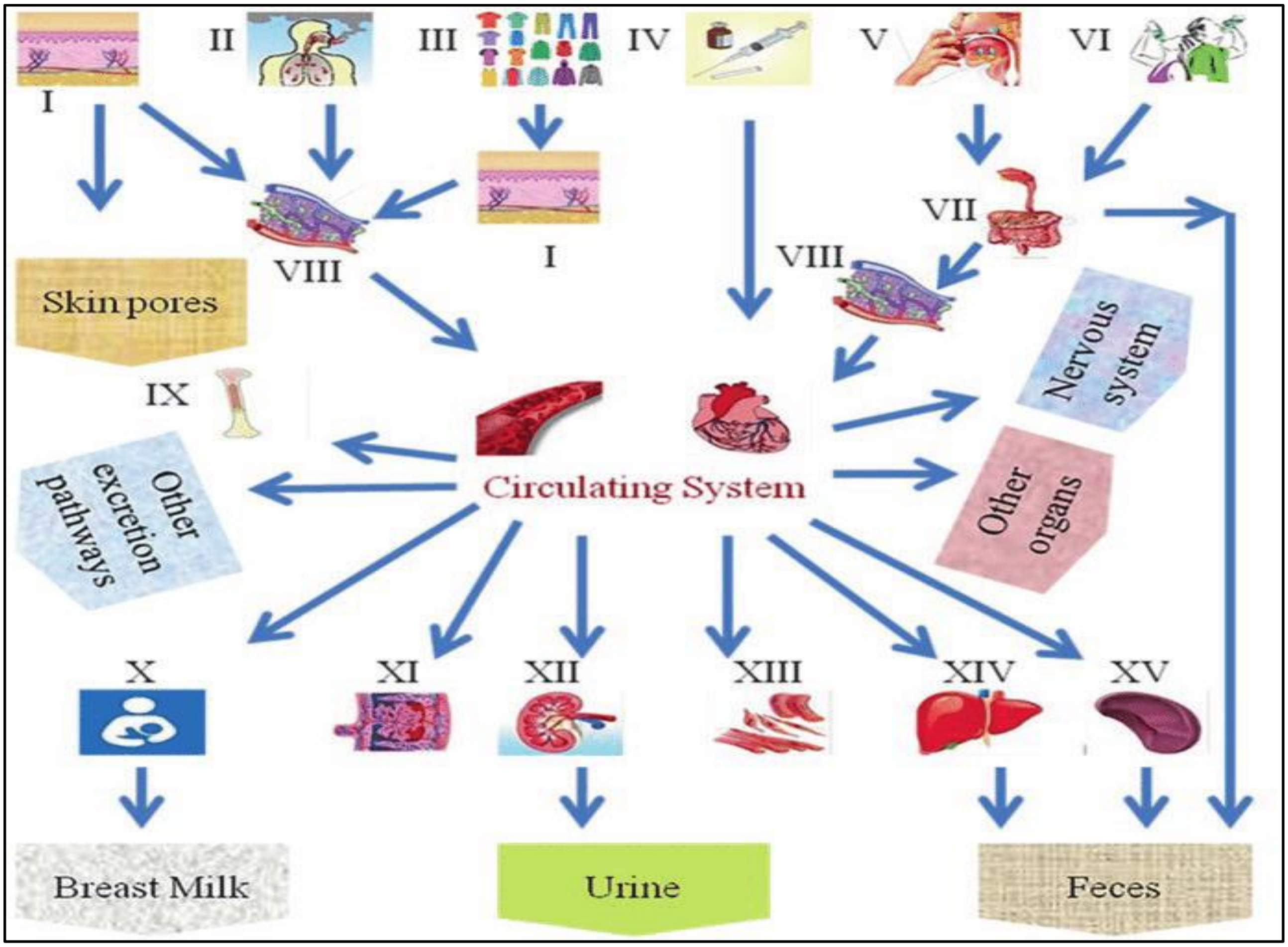

Fig.1. Diagram showing the dispersion and excretion of nanoparticles from the human body after exposure to them through various pathways. (I) Skin; (II) Inhalation; (III) Fabric; (VI) Intravenous Injection; (V) Intake of Food and Water; (VII) Gastrointestinal Tract; (VIII) Lymph; (IX) Bone Marrow; (X) Breast Milk; (XI) Placenta; (XII) Kidney; (XIII) Muscles; (XIV) Liver; and (XV) Spleen.[20]

22.3 Medical Applications

Nanomedicine is a medical application of nanotechnology.[21] Nanomedicine approaches range from medical applications of nanomaterials to nano-electronic biosensors and even potential future applications of molecular nanotechnology. In the near future, nanomedicine hopes to provide a valuable set of research tools and clinically useful devices.[22, 23] According to the National Nanotechnology Initiative, the pharmaceutical industry will see new commercial applications such as advanced drug delivery systems, new therapies, and in vivo imaging.[24] Another active area of research is neuro-electronic interfaces and other nanoelectronics-based sensors. Cell repair machines, according to the speculative field of molecular nanotechnology, could revolutionize medicine and the medical field in the future. DNA oligonucleotide ligands capable of recognizing other molecules and may even exhibit catalytic activity. Aptamers are used in a large variety of biosensors[25, 26] and therapeutics[27]. Aptamer binding depends on its 3D structure. The problem now is that there are no aptamer single crystals, so the classical X-ray diffraction cannot help. To understand the molecular basis of the complex formation, knowledge about a main aptamer spatial conformation is very desirable, but is often unavailable because of limitations of analytical methods for structure analysis. The most known method of small angle X-ray scattering (SAXS) with synchrotron source provides only the molecular shape, but not its structure. To solve this problem, recently a four-step approach to determine a true 3D structure of aptamers in solution using SAXS and molecular structure restoration (MSR) has been developed. The approach consists of (i) acquiring SAXS experimental data of an aptamer in solution, (ii) building a spatial distribution of the molecule's electron density using SAXS results, (iii) constructing a 3D model of the aptamer from its nucleotide primary sequence and secondary structure, and (iv) comparing and refining the modeled 3D structures with the experimental SAXS model. This approach was used to analyze the 3D structure of RE31 aptamer to thrombin in a native free state at different temperatures. The resulting 3D structure of RE31 has the most energetically favorable conformation and the same elements such as a B-form duplex, non-complementary region, and two G-quartets. More broadly, this study demonstrates the complementary approach for constructing and adjusting the 3D structures of aptamers, DNA enzymes, and ribozymes in solution, and could supply new opportunities for developing functional nucleic acids. The use of magnetic nanoparticles to destroy disease-causing neoplasms in the body is one of their newest applications. This direction is being actively developed, and the selective attachment of nanoparticles to cells that need to be destroyed is facilitated by their functionalization with an aptamer.[28] Ap-tamers are also widely used in cancer diagnostics and therapy.[29] Ehrlich carcinoma cell cultures are the most accessible for experiments, and recently they have become model objects for studying various effects on their destruction, including the action of a magnetic field.[30] It is observed that the magneto-dynamic therapy using the gold-coated magnetic NPs functionalized with DNA aptamers to selectively kill tumor cells in vivo.[31] The cell-specific DNA aptamer AS-14, binding to the fibronectin protein in Ehrlich carcinoma, delivered gold-coated magnetic nanoparticles to the mouse tumor. Applying an alternating magnetic field with a frequency of 50 Hz to the tumor site causes the nanoparticles to vibrate and attract fibronectin proteins and integrin's to the surface of the cell membrane. This leads to apoptosis followed by necrosis of tumor cells without heating the tumor, adjacent healthy cells and tissues. The core-shell Fe3O4@C NPs functionalized with aptamers were used successively in the experiments on the magneto-mechanical disruption of Ehrlich ascites carcinoma cell cultures.[32]

22.4 Nanotoxicology

The study of possible health concerns caused by nanomaterials is known as nanotoxicology. Nanomaterials are easier for the human body to absorb than bigger particles since they are so tiny. How these nanoparticles act inside the organism is one of the key questions that has to be solved. The behavior of nanoparticles depends on their size, shape, and surface reactivity with the surrounding tissue. For instance, they may overstress the phagocytes that take in and get rid of foreign matter. Inflammation and stress responses would result from this, weakening the body's defenses against additional diseases. In addition to the possibility that non-degradable or slowly degradable nanoparticles build up in organs, another issue is how they might interact with biological processes occurring inside the body. Because nanoparticles have a large surface area, they will quickly adsorb some of the macromolecules they come into contact with when exposed to tissue and fluids. This could affect, for instance, how proteins and enzymes regulate one another. It is challenging to generalize about the health concerns associated with exposure to nanomaterials due to the multitude of factors determining toxicity; each new nanomaterial must be evaluated separately, and all material features must be taken into account. Health and environmental concerns coexist in the workplaces of companies that manufacture or use nanomaterials, as well as in nanoscience and nanotechnology laboratories.

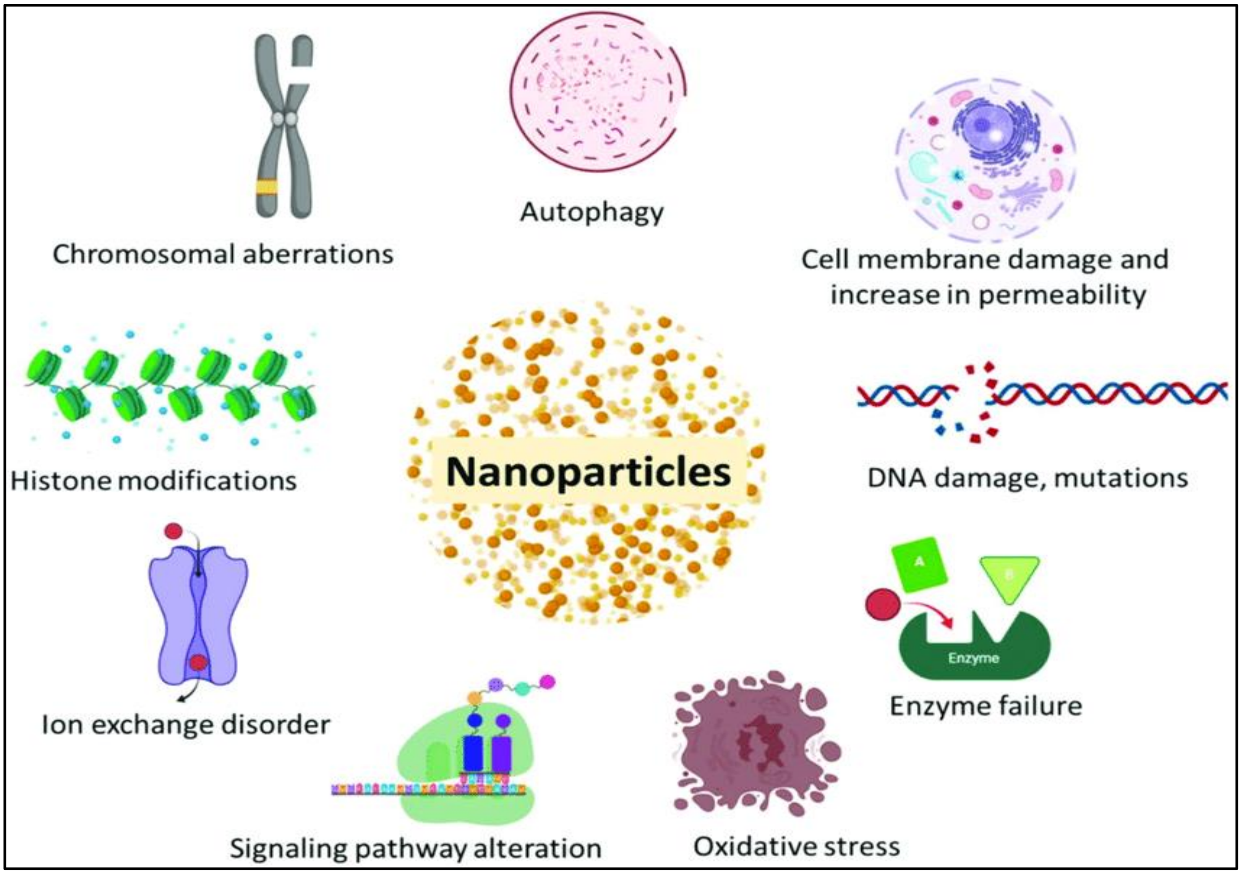

Fig. 2. Toxicity associated with nanoparticles.[24]

22.5 Environmental Impact

The two primary sources of nanomaterials in the environment are those produced naturally and those produced by humans. Examples of natural sources include volcanoes, viruses, ocean spray, dust storms, bacteria, and bushfires. The two categories of anthropogenic sources include inadvertently formed nanomaterials, such as those released by combustion aerosols, including those from motor vehicle exhaust emissions, coal fly ash, and wielding operations, and purposely manufactured nanomaterials with specific features. These might include the principally formed of metals and metal oxides fullerenes, quantum dots, nanowires, and nanotubes.[34] Furthermore, in each of these groups, nanoparticles can develop accidentally[35] This evaluation concentrates on four important features of the deliberately created ENM group. These comprise (i) the description and use of ENM, (ii) the estimation of ENM exposure, (iii) the evaluation of hazards, and (iv) environmental legislation.

The breakdown of nanomaterials (such as surface-bound nanoparticles or nanoscale coatings) can release free nanoparticles into the environment either directly or indirectly. The environment may be accessed in a variety of ways. Medicines are commonly coated, and studies have shown that these coatings can degrade either as a result of UV light-induced environmental alteration or as a result of human body metabolism[36]. About their transit and fate, aquatic nanomaterials have received comparably little research. This only serves to emphasize the need of investigating the many potential mechanisms that can alter the characteristics of nanoparticles once they are discharged into the environment. Nanomaterials or product spills during production, shipping, or disposal constitute additional routes for environmental exposure. Unless it is established that the benefits outweigh the risks, the Royal Society and The Royal Academy of Engineering warn against employing free nanoparticles in environmental remediation or other uses.[37] How much "nano-litter" exposure may impact living things and the precise toxicity pathways are currently unknown. Due to the numerous experimental difficulties and problems encountered when determining the toxicity of nanomaterials, Dhawan and Sharma recently reviewed the toxicological studies on biological systems with metal and metal oxide nanoparticles, fullerenes, and carbon nanotubes[38] and came to the conclusion that additional research is still required to definitively establish their safety and toxicity. Chemical toxicology was a major consideration in the development and standardization of the majority of toxicity assessment techniques. Yet, due to their distinct physicochemical characteristics, nanoparticles might impede or complicate traditional toxicity assessments. In conclusion, unless the ambiguities surrounding their destiny, transport, and toxicity are resolved, applications of nanoparticles that involve their direct introduction to the environment promise to be problematic.

22.5.1 Environmental Risk Assessment for Nanoparticles

Nanoparticles may be emitted as aerosols into the atmosphere, surface water, and soil depending on the kind. Aggregates, functionalized nanoparticles, bare nanoparticles, and nanoparticles embedded in a matrix are all examples of nanoparticle releases into the environment.[39] When nanoparticles are released into the environment, whether on purpose or accidentally, they disperse and wind up in the air, water, and soil, where they can persist for a very long time or be consumed by living creatures. They can provide an ecotoxicological danger as they biodegrade or bioaccumulate in the food chain. There have been instances of diesel exhaust producing nanoparticles.[40] Automobiles continue to emit lead compounds and carbon nanoparticles due to incomplete combustion. The majority of contemporary cars are equipped with pollution control systems that utilize catalysts like platinum and other noble metals.[41, 42]

It was discovered a few years ago that during the course of their lives, automobile catalysts release platinum nanoparticles with diameters ranging from 0.8 to 10 nm.[43] Although metal nanoparticles like platinum and palladium are included in the most recent catalysts created by the car industry, their sizes are different from those of conventional catalysts. It has been proven that nano-dispersed platinum group elements may penetrate mammalian tissues.[44] In biological systems, very little soluble or biodegradable nanoparticles may accumulate. Metal and metal oxide nanoparticle cytotoxicity can be reduced by utilizing organic coatings. Emerging nanotechnologies may raise environmental issues, which are related to the possible bioaccumulation of nanoparticles in natural systems. For instance, nanoparticles found in sunscreens have the potential to pollute water and soil and bioaccumulate in the food chain.[45-47] Blaser et al. found that the silver discharged is combined with sewage sludge and may move further over agricultural fields during their evaluation of the emission.[48] Engineered nanoparticles that disintegrate are more likely to do so because they are lipophilic and soluble in water (and so have the potential to penetrate fatty cell membranes).[49]

When analyzing environmental exposure, it is important to identify and quantify the sources, analyze the environmental release pattern, evaluate ambient concentrations, and assess the possibility of bioaccumulation. It is feasible to forecast how artificial nanoparticles will react in the environment using information about natural nanoparticles.[50]

22.5.2 The positive Impact of Nanomaterials on the Environment

Raising the standards for the air, soil, and water are among the global environmental problems. The business sector is actively focused on identifying pollutants (from chemical spills, fertilizer runoff, and pesticide runoff), modernizing industrial and mining sites, treating pollutants, and preventing additional pollution.

Nanomaterials could offer a practical solution to these problems. nanoparticles may be used to improve environmental cleaning processes and even provide efficient energy solutions, such as solar cells built of nanoparticles. Additionally, nanoparticles improve the quality and functioning of many consumer items.[51-53] As a result, more people are exposed to manufactured nanoparticles every day. Nanotechnology, however, has both positive and negative consequences on the environment. Nanotechnology can be used to improve the quality of water. Examples of nanomaterials that can be used for water remediation include carbon nanotubes (CNTs), zeolites, nanoparticles of zero valent iron (ZVI), silver nanoparticles, and other nanomaterials[54]. Photocatalysts include other nanomaterials including tungsten oxide, titanium dioxide, and zinc oxide. These photocatalysts can convert organic pollutants into inert molecules by oxidizing them. TiO_2 is the preferred material due to its excellent photoconductivity, good photostability, accessibility, cost, and non-toxicity. Silver at the nanoscale has an antimicrobial impact. Numerous polymeric nanoparticles are furthermore used to remediate wastewater. The use of magnetic nanoparticles for water purification also deserves attention. An important advantage of the magnetic NPs using in this field is the possibility to extract them easily from the medium by applying a magnetic field. Among others, Fe_3O_4@C NPs are the most attractive candidates for this purpose, since they combine good sorption properties of carbon with high magnetic properties of magnetite (Fe_3O_4). Many authors have devoted their efforts to application of Fe_3O_4@C NPs as adsorbents of various substances. These NPs were used as sorbents of heavy metals (Cu, Ni, Co, and Cd)[55]. It was shown that the carbon layer is responsible for the effective adsorption of the polycyclic aromatic hydrocarbons by Fe_3O_4@C NPs[56]. Fe_3O_4@C NPs obtained by the light hydrothermal reaction of glucose with iron were used as the magnetic solid-phase extraction sorbent of brominated flame-retardants and pentachlorophenol[57]. The number of publications dealt with the study of the dyes adsorption by the Fe_3O_4@C and Fe_3O_4@SiO_2 NPs [58-60]. The high adsorption capacity of magnetic NPs together with easy magnetic separation and the possibility of their reusing noted in these works stimulate the search for new technological solutions for further improving the characteristics of adsorbents based on such kind of NPs.

Another cutting-edge technique that may be utilized to purify water in residential, commercial, and industrial settings is nanofiltration. Molybdenum disulphide (MoS_2) is used to create an energy-efficient membrane that filters five times as much water as conventional ones. To wipe up oil spills in bodies of water, a paper towel constructed of nano-fabric, which is weaved from tiny wires of potassium manganese oxide, has been developed. Nanotechnology thus offers a way to treat the polluted water and stop further pollution. It is possible to filter airborne dangerous gases using nanotechnology. But first, we must utilize accurate sensors to pinpoint the contaminants' molecular locations. Heavy metal ions and radioactive elements can both be detected by a sensor known as a nanocontact sensor. These sensors are portable, affordable, and simple to use on-site. Currently, NO_2 and NH_3 gas detection is done using single-walled nanotubes (SWNTs).

In addition, SWNTs sensors have the potential to attain high sensing activity at ambient temperature, in contrast to traditional sensors, which function between 200 and 600 °C. For the detection of pesticides, heavy metals, and VOCs, cantilever sensors have been created. Toxic gases including NO_x, SO_2, and CO_2 may be absorbed using a mixture of CNTs and gold particles. Due to its enormous surface area, manganese oxide, a distinct porous nanomaterial, provides outstanding hazardous gas adsorption. By deploying specific sensors to identify toxins, we may so contribute to the sustainability of both human health and the environment. Therefore, nanotechnology presents a novel approach for lowering waste production, greenhouse gas emissions, and the discharge of hazardous chemicals into waterways.[61]

22.6 The Positive Impact of Nanomaterials on Health

The use of nanotechnology is expanding quickly in a variety of fields, including industrial applications, medical imaging, illness detection, medication delivery, gene therapy, and cancer treatment. Due to its many potential benefits for human health and the possible threats to human health, nanotechnology is at the forefront of the rapid development of healthcare products.[62, 63]

When shrunk to a nano molecular size, many tiny particles that are currently thought to be innocuous are likely to develop special properties and might show harmful biological effects. It is well established that the physical and chemical characteristics of the particle will affect the toxicity of designed NP. The same material that is not on the nanoscale can have different properties in nanomaterials. The size of the NP, together with its surface area, aggregation state, crystal structure, surface charge, and porosity, are crucial factors in figuring out how poisonous it is. Nanoparticles have a variety of special health advantages; molecular imaging employs them to identify, measure, and visualize cellular and molecular alterations that take place both in vitro and in vivo.[64] Fluorescent biological probes consisting of organic dyes are frequently used in biology because they are inert and may interact without losing sensitivity in a variety of cellular functions. Nanoparticles can be used as probes in vivo by attaching them to protein, antibody, and nucleic acid molecules. These nanoparticles might then be used as tools to see and quantify molecular processes taking place inside the body. In a broad spectrum, they have good brightness, photostability, and absorption coefficients.

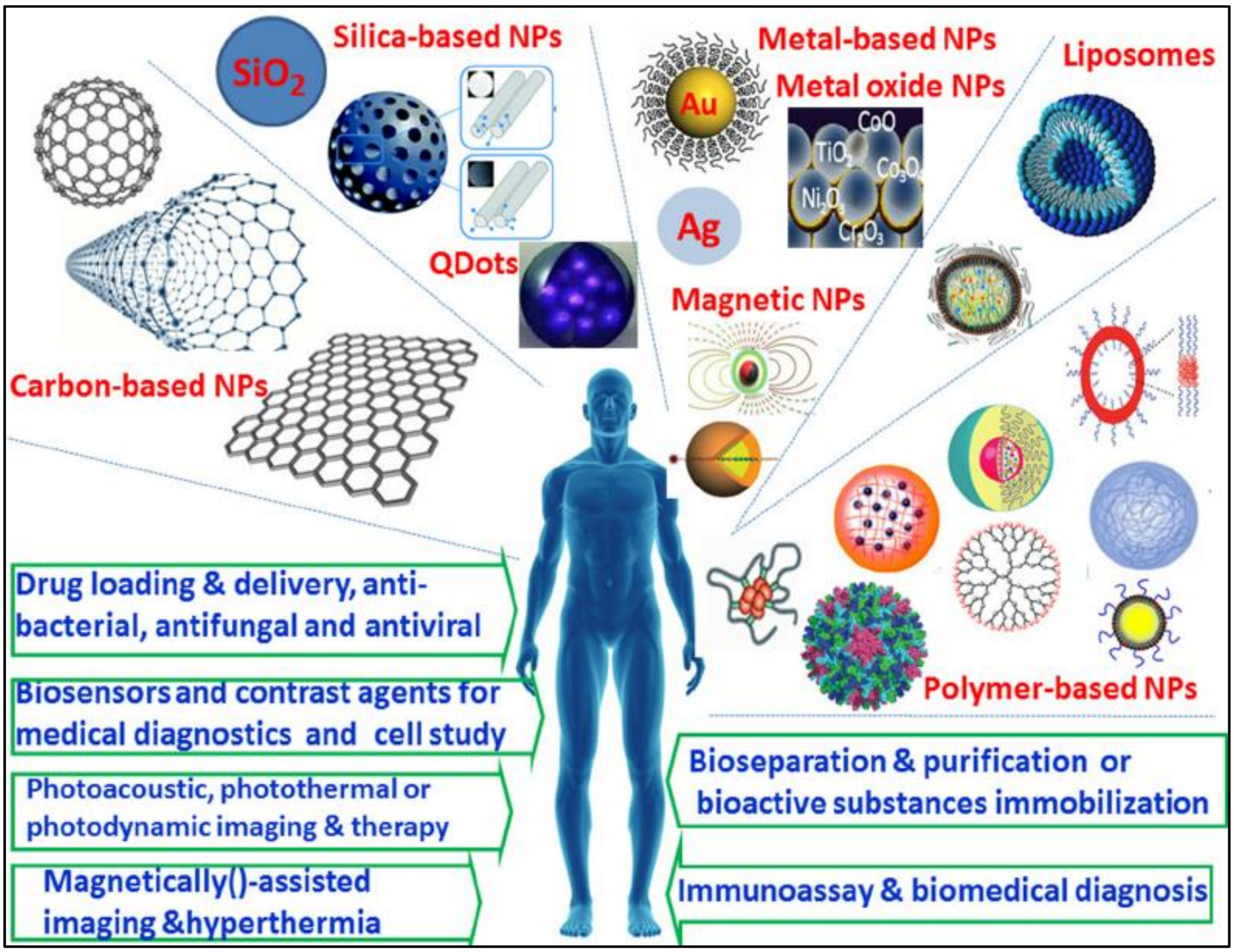

Fig. 3. Nanoparticles and their applications in biomedical fields.[65]

Using nanoparticles for site-specific, targeted medication administration increases bioavailability, has fewer adverse effects, is less hazardous to other organs, and is less expensive[66, 67]. The investigation of tumor-specific thermal scalpels to heat and burn tumors represents an attractive prospective application of nanoparticles in cancer therapy. It is possible to stop the growth of a tumor by utilizing near infrared-absorbing polyethylene-coated gold nano-shells of 130 nm. Gold and silver nanoparticles, which are utilized in wrinkle creams, deodorants, and burn treatments, have potent antifungal, antibacterial, and anti-inflammatory qualities. They are non-cytotoxic, very stable, biocompatible, and neutral.[65]

22.6.1 Enhanced Therapeutics, Diagnostics, and Sensors Powered by Nanotechnology

A small chip may contain up to 64 nano-sensors, each of which is capable of detecting the tiniest levels of hazardous gases. It requires a very little amount of electricity and is made to plug into a cell phone. In order to monitor crop disease and moisture levels in agriculture, researchers are also creating sensors. These nanotechnology-enabled sensors will aid in securing firefighters, troops, and our food supply due to their small size and versatility.[68] The fact that a patient's body doesn't absorb the complete therapeutic amount is a significant challenge for modern medicine. Using nanotechnology, scientists can more accurately deliver pharmaceuticals to specific organs and tissues, and they can create medications such that the active component penetrates cell membranes more quickly, resulting in a reduction in the overall amount of medication needed.

Nanotechnology may also change medicine delivery by tackling concerns like how to maintain the release of pharmaceuticals in the body and improving bioavailability—the quantity of active substance per dosage. Some pharmaceuticals can now be transported via "nano-vehicles." Stavudine and zidovudine, two HIV drugs, have been encapsulated in liposomes, which may transport the drug payload by bonding with cell membranes, in carriers with a size range of 120 to 200 nanometers. Since the half-lives of both of these drugs are short, the liposome coating could help them stay active for extended periods of time.

Many targeted drug delivery methods utilize dendrimers, which are branching nano-molecules, and fullerene "buckyball" cages.[69]

22.6.2 Fluorescent quantum dots

Glow-enabled nanoscale semiconductors can be used as biosensors to identify illness. In comparison to traditional organic dyes, quantum dots, also known as nanocrystals, have a number of benefits, such as the capacity to adjust their luminescence to a wide range of frequencies and a much slower rate of in vivo degradation. Fluorescent quantum dots can be combined with antibodies that target cancerous, TB, or HIV-infected cells. They might also be used to detect malaria by making fluorescent quantum dots particularly target the protein that makes a mesh in the inner membrane of blood cells. Because the geometry of this protein network changes when cells are infected with malaria, researchers may identify malaria infection by the shape generated by the dots.

	POSITIVE IMPACTS	**NEGATIVE IMPACTS**	**FUTURE PROSPECTS**
1	Development of medicine & Economy.	Long term regulatory measures for safety or lack of unified set of global regulations.	Tumor targeting delivery system
2	Better stability of unstable active ingredients.	Potential to be Genotoxic if unregulated.	Drug discovery/vaccine
3	Medical robotics (better diagnosis & treatment).	Cultural, economic & military (defense) changes.	Implantable delivery system
4	Good biocompatibility, biodegradability & bioavailability.	Products/byproducts for manufacturing nanomaterials released in surroundings or penetrating the human body.	Nanoparticles for Gene delivery
5	Targeted drug delivery.	Costlier to be used by majority.	Molecular diagnosis

6	Detection of nutrients & pathogens by Biosensors, quantum dots. Nano-clay for water retention.	Nanotoxicity (uncertain cytotoxicity of the nanostructured materials incorporated or migrated in food products.	Biosensors, nanobots, xenobots, bio-labels

Table 22(a): Impact and future prospects of nanomaterials

22.6.3 Health monitoring

Nanotubes and nanoparticles can be used as glucose, carbon dioxide, and cholesterol sensors for in-situ monitoring of homeostasis, the body's system for maintaining metabolic equilibrium. Nanotechnology has also improved the treatment of tuberculosis. For the present TB therapy, a complex medication regimen that is spread out over several months is required. A lot of folks either don't take their meds as prescribed or stop taking the course altogether. Drug formulations based on nanotechnology breakdown more gradually and supply more of the active ingredient in fewer doses. To allow for continued delivery of the therapy, the drugs are encapsulated in biodegradable polymers such microspheres and liposomes. Polylactide co-glycolide nanoparticles have been used effectively in drug carrier studies for TB because they degrade well and do not elicit an immunological response. Nanoparticles might potentially serve as the basis for an aerosol TB vaccination. There is no requirement for trained personnel to administer the vaccination because it is stable at room temperature without a needle. This is important in distant locations without a strong cold chain.

Nanotechnology may advance vaccination to new heights by creating substitutes for injectable vaccines for diseases that affect the underprivileged. Injectable vaccines could be helpful if the latent virus is combined with nanoparticles to strengthen the immune response. The development of a pandemic influenza vaccine is also being done using this method.

22.6.4 Drug delivery using nano-capsules

Nano-capsules, which have a millimeter-thin diameter, can have an antibody coating on their surface to help guide blood flow to artificial tumors. An instantaneous blast that occurs when the capsules arrive at the tumor causes them to instantly open and release their medicinal contents. There are small gold particles in the range of 6 nm, or 6 millionths of a milli-meter, on the surface of the polymer. These particles cling across and are particular to the laser light, guiding the capsules

to position their drug load capacity when it is needed. When the gold specks are exposed to near infrared light, they instantly melt without damaging the surrounding material, revealing the rupturing of the capsule.[70]

22.6.5 Nano-capsule bandages to combat infection in the future

The traditional dressings must be removed if the skin becomes damaged or the healing process is slowed. In contrast, when a wound becomes infected, nano-capsular dressings immediately release antibiotics. They don't need to be removed, which increases the likelihood that a wound will heal without leaving a scar. Additionally, ulcers can be treated with nano-capsular bandages, which are most frequently applied by soldiers on the battlefield. These medicinal dressings target the treatment before the infection worsens by releasing antibiotics from nano-capsules activated by the presence of disease-causing pathogenic or causative bacterial organism. The capsules containing the antibiotics, which serve as dressings, are ruptured by the bacterial toxins.

The development of formulation methods, notably interfacial nano-deposition and interfacial polymerization, is aided by nano-capsules. The ability to release them as monodisperse particles with unique biological, electrical, optical, and magnetic characteristics is another advantage. Because they are created to generate contents in response to a specific bimolecular triggering action mechanism, they are restricted in drug delivery systems. Agrochemicals, wastewater treatment, genetic engineering, cosmetics, cleaning products, and adhesive components are just a few of the areas where nano-capsules are useful. Enzymes, adhesives, catalysts, polymers, oils, inorganic micro- and nanoparticles, latex particles, and even living cells are all encapsulated using them. They can be utilized to distribute active medicinal substances, to sum up (APIs). They offer cutting-edge, efficient drug delivery technologies for the foreseeable future.[71] The nano-capsules market has an interesting and promising future. This is a technology that will continue to offer answers for various major difficulties, as evidenced by the expected industry growth and the expanding number of economically relevant applications for the sector.

It will be far more effective, for example, to administer and target smart drugs that can be tailored to a patient's requirements. The stability and bioavailability of pharmaceuticals can be improved by developing transdermal drug delivery devices.

22.6.6 Nanobots In Medical Field

Nanobots are robots that employ nanotechnology. Emerging technology known as "nano robotics" produces machines or robots with parts that are at or very close to the scale of a nanometer. The nanoscale technical gaps in physics, chemistry, and biology will be bridged in part by nanobots. With the help of these nanobots, new techniques and items will be developed for use in technical

and medical-pharmaceutical applications. Nanobots are also suitable candidates for complex therapies due to their small size. Drug delivery systems and contrast agents are both made of nanobots, they can be utilized for drug delivery in a very active way. Drugs typically go through the entire body before they reach the location where the sickness is present. The medicine can be targeted to a particular place using nanotechnology, which can lower the likelihood of any potential side effects.[72] More specifically, the term "Nano robotics" refers to the engineering field of nanotechnology that focuses on designing and creating nanobots with sizes starting at 0.110 micrometers and made of molecular or nanoscale components. The phrases nanobots, nanoid, nanite, nanomachine, or nano-mite are used to describe the nano devices that are currently the subject of research and development. Although several crude molecular machines and nanomotors have been tried, nanomachines are largely used in the research and development stage.

These nanorobots frequently transport biochemical payloads throughout the system and block local tumor blood flow, which may result in tissue death and cause the tumor to shrink. The development of nanobots and their application to medicine is now under way. When injected intravenously, nanobots used in medicine target cancer cells and repair damaged tissue because they are built to perform specific biological tasks. When research projects and nanobots are joined, a new benchmark in the development of medical analysis is attained. Humanity has made significant progress in terms of procedure safety and dependability. Endoscopy is one of the methods that has been created to aid in diagnosis and provide a better understanding of the body's inner workings.[51] But as we are all aware, technology must eventually be phased out. And much as historical practices have evolved to address the shortcomings of their forebears, nanorobotics will work to address the following flaws in current medical technologies:

i. Remove unhealthy tissue layers that require time to recover.

ii. Although anesthesia can significantly reduce pain, it only has a temporary effect.

iii. For delicate surgeries like eye surgery, there is still no 100% success rate.

iv. The patient's life is entirely in the hands of the operator, surgeon, or physician in any invasive technique. It is dangerous because a single error could result in the patient's death.

The following are the key advantages of this technology:

i. No or little tissue trauma.

ii. Much quicker healing time.

iii. Less after-treatment care is necessary.

iv. Rapid reaction to an unexpected development.

v. Monitoring and diagnosis from the interior.

Nanobots can carry payloads like medications or healthy cells to a precise spot in the body by being steered externally as instructed by a computer. These nanobots' ability to go through normal cellular channels is an extra benefit.

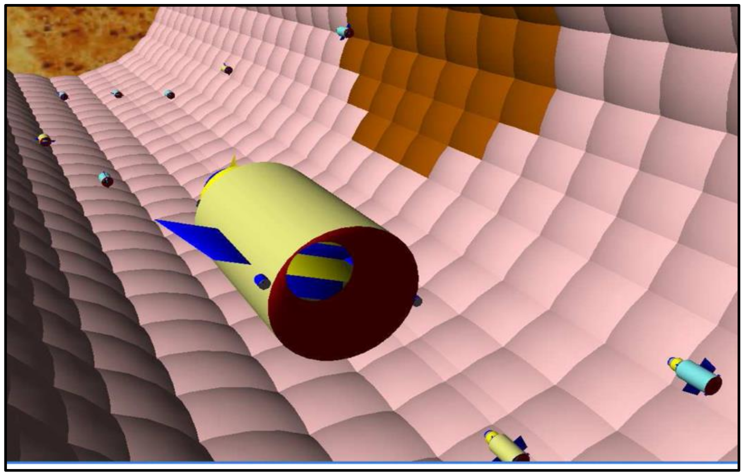

Fig. 4. Nanobots in medicine and drug delivery.[72]

The primary drawback of designing nanobots is that it is expensive and involves numerous complexities. The power supply is the biggest challenge. More research must be done in order for the bots to defeat the body's immune reaction. If terrorists employ nanobots improperly, they might potentially be turned into bioweapons and pose a threat to civilization. Nanobots are foreign to the body since they can have catastrophic consequences if nanobacteria are present. The body contains a lot of foreign objects, so biodegradability will be a big issue. Thus, it is necessary to take strong measures to address each of these shortcomings.

22.7 Development of a "Global Super-brain"

A third exciting development in nanobot research is the use of nanotechnology to build a "global super-brain" where potentially, human cognition might be transmitted to an artificial interface, producing a "brain-cloud interface." Theoretically, in the future, nanobots might wirelessly transmit brain data to a network of cloud-hosted supercomputers, enabling data extraction in real-time and brain-state monitoring. But before it can be implemented, this use of nanotechnology must go through a rigorous period of study and design, as well as go beyond the technology's ethical and moral implications.

22.8 Xenobots

Recent research has paved the way for the creation of xenobots, small robots with a length of less than 1 mm and made of 500–1000 living cells. They may be found in many different straightforward forms, some of which include legs. Studies have shown that they can move tiny objects, travel effectively in a linear or circular pattern, work together with other xenobots to complete tasks, and live for around ten days. Scientists think that these xenobots might be developed in various ways that could help human, animal, and environmental health, despite the fact that their position as "programmable living robots" made from live, organic tissue raises ethical questions. Xenobots future is somewhat uncertain due to ethical concerns, scientists working in this field are enthusiastic about their potential applications in removing microplastics from the ocean, removing toxins and radioactive materials from hazardous locations, improving the efficiency and effectiveness of targeted drug delivery, and repairing cells and tissues.[72, 73]

Xenobots could be used to remove plaque from our arteries, remove radioactive waste from the environment, collect microplastics from the ocean, convey drugs inside of people, and clean up radioactive waste. The xenobots are suitable for internal drug administration since they may endure in aquatic settings for days or weeks without extra nutrition. In addition to these immediate useful activities, the xenobots may aid scientists in their understanding of cell biology, paving the way for future improvements in human health and lifespan.

22.9 Conclusion and challenges

Nanotechnology is developing quickly, and this will undoubtedly have an impact on human health, the environment, and toxicology.[75] It is without question how important nanotechnologies are to our wellbeing, but it is even more important to research any potential negative effects. Nanomaterials' safety, toxicity, and health implications have lagged considerably behind their production.

This is believed to be due to the lack of specific guidelines and widespread consensus among researchers regarding appropriate experimental procedures or study designs. It also depends on the unique properties of nanoscale materials,[76, 77] which provide difficulties for the toxicological assessment of novel nanomaterials. Despite a significant rise in publications in recent years, all of these issues lead to variable and erratic outcomes and obstruct the advancement of this field. This study attempts to critically compile and evaluate the many methods and challenges connected to the health and safety implications of nanomaterials for human health and the environment using the abundance of knowledge already accessible. The preparation procedures for typical nanomaterials and prospective applications have been briefly explored. The developing science of nanotoxicology will greatly contribute to the development of safe and sustainable nanotechnology. A deeper comprehension of the dangers posed by nanoparticles in the environment and on humans is crucial for the development and use of various nanomaterials in the future. A multidisciplinary team effort involving material scientists, molecular biologists, toxicologists, and physicists is necessary to create nanotoxicology. One of the numerous topics of nanotoxicology is the comprehension of biological responses to nanomaterial exposure and the processes underlying them. It is important to recognize and document in the literature any challenges that were experienced when conducting various in vitro and in vivo studies on nanomaterials. This would make it easier for beginners to figure out the problem and help them save time and effort. Evaluation of the safety aspects of the particles must be given top priority due to the anticipated large-scale production of the particles and the likelihood of human exposure, either directly through the use of cosmetics, drugs, or drug delivery devices, or indirectly through distribution through the air, water, and soil.

There is a need for better environmental risk and life cycle assessment, as well as defined sustainability targets, in the governance of technical innovation in the field of nanotechnology. In many aspects, nanotechnology is an example of a technologically-based attempt to solve a problem that actually requires social, economic, and political solutions.

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