A review on the impact of nanotechnology and nanomaterials on society

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ABSTRACT

Nanotechnology and nanomaterials are not longer simple concepts that scientists such as Feynman and Taniguchi described with a futuristic outlook in the middle of the XX century; their applications and development have become part of the daily life. With the evolution and the development of new nanoscale materials is necessary to make a detailed classification, characterization and standardization of their properties. This classification, characterization and detailed standardization should also include a careful and continuous work to determine what the effects will be in such varied contexts as ethical, social, economic, geopolitical, human health, environmental and even the legislation that must be created and implemented to regulate them. This document identified some features of nanotechnology that potentially give rise to ethical and social questions, economic impact and legislative needs.

KEY WORDS: Nano materials, Nanotechnology, Impact on Society.

1. INTRODUCTION

The term "nanotechnology" was first mentioned by Norio Taniguchi in 1974 as "the one that will enable the manufacturing of objects or devices with an accuracy of the nanometer order, that is to say 10^{-9} meters in length" (Taniguchi, 1974). It is not an easy task to define exactly when the development of new materials crossed the limit of the nanoscale, since the 1950 and 1960 some efforts were made in the modification of the atomic structures of silicon and germanium semiconductors, alloys with shape memory, development of catalysts with supported catalyst particles below 20 nm, among other examples. Towards the end of the seventies and during the eighties an expansion was observed in the research and development of new materials at the nano-scale, this expansion was characterized by the tendency in the manipulation and re-configuration of materials at the molecular level and/or the atomic level, which allowed to establish a constant increase of the study of the nanotechnology during the last 20 years. The current trend of development began in the 1980s, with the achievement of important advances such as the first tunneling microscope in 1981. This tool allowed to characterize and manipulate materials atom by atom. The dynamics of research and development in the area of nano materials is reflected in the 1990s with the establishment of study centers dedicated exclusively to the area, Figure.1, presents the variation of the number of research centers in nano materials in countries in the developed world (Santo, 2006; Coccia, 2010). At the end of the 20th century, countries such as Japan, the United States and the European Community maintained leadership, each with more than 100 research centers, for the first decade of the 21st century. China and South Korea doubled and tripled the number of research centers in nanomaterials and nanotechnology.

Just as there are varied governmental and private efforts to develop the great potential of the applications that nanotechnology and nanomaterials can have, there must be a careful and continuous work in determining what the positive and negative effects will be in areas that may not be as evident as their immediate applications but which in the long term will prove to be of prime importance, monitoring and constantly evaluating to avoid that the negative effects outweigh the positive effects. Among the fields in which the effect of nanomaterials and nanotechnology should be monitored area: ethical and social, economic and geopolitical, effects on human health and on the environment, even in the legislation required to regulate them.

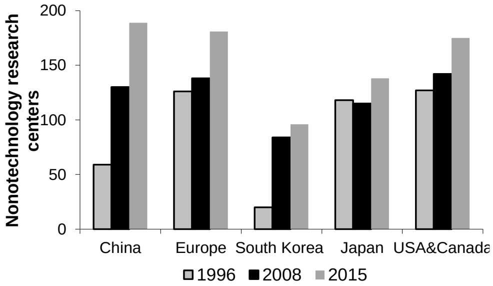

Figure.1. Increased number of research laboratories dedicated to nanotechnology in developed countries

Ethical and Social Impact: A good number of products that make use of the properties of nanomaterials are already available in the market and therefore in contact with the consumer; In the next few years, the massive entry of products including nanomaterials into their formulation (pharmaceuticals, diagnostics, electronic devices, energy production and storage, among others) is expected to exponentially growth (Sahaym and Norton, 2008; Lu, 2009). The continuous commercialization of nanomaterials raises important social and ethical questions; The current trend assigns great importance to the assessment of the environmental impact of new technologies and focuses on the evaluation of science-based risks, leaving aside the social and ethical values involved in the incorporation of new technologies and products in the society (Grunwald 2008; Petersen 2009; Spagnolo and Daloiso 2009; Sparrow 2009). Some characteristics of the nanotechnology have been identified that will potentially lead to the emergence of ethical and social problems, such as:

Invisibility: Once applied is difficult to track its effects.

Rapid development: The rapid pace of their progress creates problems in determining their possible effects and the appropriate response to them, especially in their long-term implications.

Use for military purposes: The application of nanotechnology for military purposes may contradict the use of nanotechnology in the creation of welfare.

Planetary effects: Nanotechnology can influence both positively and negatively in countries and societies that are not directly involved in the development of nanotechnology.

Risk of disparity: Nanotechnology could exacerbate the technical / economic imbalance between developing and developed countries.

Economic Impact: It is very uncertain to try to predict the impact nanotechnology and nanomaterials will have on the world. New developments in methods of agricultural production or food preservation could reduce the nutritional problems of a constantly growing world population. The advance in diagnosis and treatment of diseases could improve the outlook for patients with diseases that are currently required costly and invasive treatments. The development of modified catalysts capable of economically generate hydrogen from water and their subsequent conversion to electric energy in combustion cells that use electrodes and separation membranes manufactured using technology will respond to the serious problem of energy generation that exists today, reducing the polluting effect of the main existing sources (fossil fuel combustion and atomic energy). More efficient electronic components will reduce the energy demand and more resistant building materials, with better properties of heat, sound and light transfer would make the level of comfort of the houses and offices of the future unattainable for the present technologies. These expectations are based on a set of priority research areas, identified by several authors and research entities, that can be grouped into twelve basic subject, among which semiconductors, drugs and tissue engineering, control and remediation Environmental, defense, security and protection, among others, are recognized as the prime importance (Jung and Lee, 2014).

However, like other industrial advances in the past (steam engine, nuclear power, developments in informatics and electronics, among others) nanotechnology could have the effect of widening the technical and economic imbalance between developed and developing countries. This inequality may reflect progress in preventive and corrective medicine, transportation, energy supply, etc., which could be primarily available to those sectors of society that have the means to pay for them. Many new applications of nanotechnology and nanomaterials will have a positive impact on reducing consumption and the efficient use of natural resources. However, in the short and medium term the economic impact on certain countries, especially developing countries, will be reflected in the loss of income from the efficient use of natural resources whose economies depend to a large extent on their exploitation. It is clear that societies that invest in the development of nanotechnology and nanomaterials will have the potential to benefit their citizens, their environment and their economy in the same way as technological revolutions in the past determined the countries that were at the forefront of the world (for example the industrial revolution in England). Countries must bear the costs of training the professionals who will develop this technology; it is clear that the training of these scientists is costly and once trained, the countries must provide the means to apply their knowledge and develop their potential in the same society that formed them and thus avoid possible migration to countries that provide better conditions for their work. A structured development policy in nanotechnology and nanomaterials must be combined with the clear definition of the objectives and needs to be solved and with the visualization of the problems that will be faced in the future, in accordance with a sustainable social economic development (Delgado-Ramos 2014).

Although it is difficult to assess the economic impact of nanotechnology and nanomaterials at present, it has been estimated in billions of US dollars. For the year 2015 the impact of nanomaterials in the electronics industry is estimated in the order of 450 billion US dollars (Kobayashi 2004; Luther, 2005; Losch 2006; Hullmann 2007). The historical trend shows that the countries that have invested in the research and development of new technologies, reflect their effort in the revenue they generate. An initial indication of the interest of certain countries to participate in this development is shown in the increase of the research laboratory established between 1990 and 2015 as discussed previously (figure.1). Recent data also reflect how certain countries concentrate growth rates in terms of the creation of companies engaged in the production and marketing of nanomaterials or nanotechnology services, as shown in Figure.2.

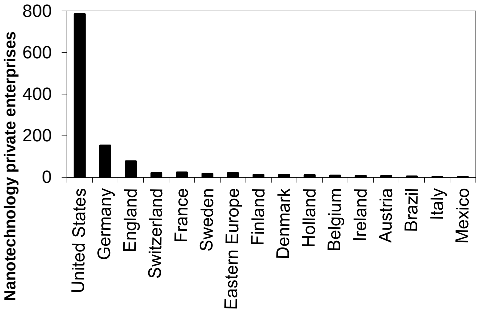

Figure.2. Number of nanotechnology companies in first world countries by 2015

Looking at the information reported in Figure 1 and Figure 2, it is clear that the US leadership in the creation of numerous research centers is generally integrated with the research and development efforts of universities and companies. The government of this country has incorporated the nanotechnology as a priority sector in its 5 to 10 years strategic plan. The European Community has also emphasized the priority nature of nanotechnology within the framework of the Seventh Framework Program for Science and Technology. Other countries that have clear policies to encourage nanotechnology are Australia, Japan, South Korea, India, China and Israel through plans and investments specifically for nanotechnology research and development.

In 2003, the nanotechnology research budget in the United States, Japan and the European Union was estimated at $ 4 billion; Particularly Japan, increased its investment from 75 to 470 million dollars in the period from 1998 to 2003. The European Union in 2005 published the "European Action Plan for Nanotechnology", establishing the importance and strategic value of Nanotechnology in the economic development and well-being of the continent. At the Latin American level, in Brazil the area of nanotechnology has aroused the interest of large business groups representing a revolutionary and innovative character for this country, recognizing its importance officially through the Ministry of Science and Technology, and further deepening its implementation through the National Nanotechnology Program (PNN) (Mendoza and Rodriguez, 2007; Fonseca and Pereira 2014). In Colombia, despite the fact that until recently there was no clear national policy to promote the development of nanotechnology, the country is working in the creation of several research groups, a National Council and a Network Center (Garcia 2008). These groups are working on the interaction and integration at local, regional and international levels. One example of these integration efforts are the Colombia-US Workshop on nanotechnology held in 2013 and 2015.

Impact on Human Health:

Benefits of nanotechnology and nanomaterials in human health: Research and development efforts in the last decades in the field of nanotechnology have allowed advances in applications that can improve the detection and treatment of diseases that affect the human being. Nanotechnology can improve disease detection by improving sensitivity, selectivity, diagnosis time, and availability of test equipment (Smolkova, 2015).

Several types of nanomaterials, including nano-wires, quantum dots and nanoparticles, are investigated to create nanosensors designed to detect diseases (Veigas, 2012; Mura and Couvreur, 2013); quantum dots made with semiconductor materials have the potential to enhance biological imaging for medical diagnosis given their ability to be optically active over a broad spectrum of wavelengths that can be used to locate and identify specific types of cells and biological activities (Stephen, 2011; Ang and Yung 2012; Dasilva, 2012). An example of this application is the early identification of atherosclerosis, through nanoparticles that specifically interact with the atheromas in the arteries.

The ability of early detection is not only reduced to its identification by means of images, true clinical laboratories can be made in microchips that act as biosensors, which are high performance tools for the analysis of the interaction between drugs and biological membranes or living cells, so it is likely that a small amount of blood can be diagnosed several times at the same time (Ang and Yung 2012; Dasilva, Diez, 2012; Tong, 2012; Mura and Couvreur 2013).

Another field of research in nanotechnology with application in medicine is the manipulation of stem cells for use in regenerative medicine. Nanomaterials such as carbon nanotubes have been used for imaging, delivery of genes and drugs, and also as support material for tissue engineering and stimulation of cells (eg, in the spinal cord or in brain cells) (Akhavan, 2012; Kaur and Singhal, 2012; Mitsiadis, 2012; Alshatwi, 2013).

Nanotechnology has not only contributed to the efficient detection of diseases, but also to the production of drugs that interact at the molecular level. Cancer is a good example of this application, nano-drugs with specific markers to interact only with cancer cells, which can be efficiently localized and destroyed. In the same way, specific markers can be developed to identify bacteria, protozoa, worms and other parasites that cause diseases such as tuberculosis, throat infections, leprosy, malaria, among others (Nicolini, 2012; Steffens, 2012; Zhao, 2012; Zhu, 2012).

Disadvantages of nanotechnology and nanomaterials in human health: The way that nanoscale materials interact with biological systems is little known and although the benefits of some nanomaterials are obvious, there is also the possibility that some may be harmful to health. Existing knowledge about the toxicity of nanomaterials is limited; Inhalation is one of the most frequent routes of exposure to nanomaterials and its effect is intrinsically related to the size of inhaled particles; Disaggregated particles smaller than 100 nm present higher levels of toxicity than aggregates of nanoparticles of the same material (composite bodies of several nanoparticles) and whose joint size is on the order of 300 to 700 nm (Oberdorster, 1992; Chalupa, 2004; Shvedova, 2006; Oberdorster, 2007). The results indicate that in the range of 10 to 90 nm the percentage of nanoscale particles deposited in the pulmonary alveoli increases from 26 to 47% while for values greater than 100 nm this percentage decreases. In terms of particle deposition in the respiratory tracts, this percentage continuously decreases as the particles increase in size (Oberdorster et al. 1994); studies have shown that the effects of inhaled particles depends not only on the amount of inhaled particles but also on the surface area of the particles (Oberdorster and Yu, 1990; Driscoll, 1997).

Skin exposure to nanoparticulate materials is mainly represented by the use of consumer products that are directly applied to it (cosmetics, sun protection products, medicinal products, among others). The skin consists of three layers: the epidermis, the dermis and the subcutaneous layer. The outer layer of the epidermis is called the stratum corneum (SC) and consists essentially of dead cells. Most studies concerning the interaction of nanomaterials in the skin have focused on determining whether pharmacological formulations have the ability to penetrate the different layers. TiO_2 particles are an important ingredient of creams and formulations for sun protection (UV radiation); studies on the skin penetration of TiO_2 microparticles have shown that they penetrate SC but do not reach the inner layers of the dermis (Lademann, 1999). However, particles of the same material in sizes ranging from 5-20 nanometers penetrate all layers of the skin and may interact with the immune system (Hosmer, 2011). Additional factors related to the properties of the nanomaterial in contact with the skin (dose, vehicle, reactivity, etc.) have been considered as important variables to determine their effects (skin age, anatomical site of exposure, wounds or exposed lacerations, etc.); there is evidence that skin with wounds or lacerations facilitate the migration of nanomaterials, especially in body sites where the skin tends to be thin (Hostynek, 2003).

It is important to assess the effects of nanomaterials in the digestive tract as different types of nanomaterials are ingredients in numerous food products, in addition to the possibility that some food may be contaminated by contact with surfaces containing nanoparticulated material (containers, kitchen utensils, etc.), these nanoparticulated materials may have the ability to bioaccumulate in organs such as the kidney and liver. Although the absorption of nanoparticles in the gastrointestinal tract is apparently low, the health risks for ingested nanomaterials are still confused as are other types of exposures, depending on the specific characteristics of the material (size, surface structure, chemical composition, etc.). There is not much data available on the toxic or inflammatory potential of nanomaterials; it has been reported that nanoscale particles of vanadium oxide have cytotoxic effects on cells of the digestive tract, effects similar to those caused by nanometric zinc oxide particles (Moos et al. 2010). Some studies in vitro (rats and mice) have shown damage in the molecular structure of DNA and high toxicity of nanoparticles of various materials, the organs most affected were the liver and the walls of the small intestine (Dybdahl, 2003).

Impact on the Environment: Nanotechnology, like any other technological advance, has the potential to bring great benefits but in the same way generate new environmental impacts and risks; these can be generated from the very moment of its manufacture (if it requires the disproportionate use of natural resources), throughout its useful life and during its final disposal. There has been a wide-ranging debate on the effect on organisms and the ecosystem on the industrial and commercial use of nanomaterials. In the literature, reviewing the potential effects of nanomaterials on human health, we observed a disparity in the efforts made to understand the effects of nanoparticles in controlled environments and under constant supervision, in contrast to the notorious absence of scientific literature on the environmental toxicity in external conditions and subjected to all the existing variables of the environment. Outside the controlled environment of the laboratory, one of the major concerns is the potential unrestricted mobility of nanomaterials in the ecosystem (Nemmar, 2001). This same mobility, that is a concern in terms of estimating their diffusion, is the property that makes them attractive for applications in which they are wanted to use as transportation elements, such the supply of medicines, given their ability to join other molecules (Baun, 2008), an effect known as the 'Trojan horse'.

Although research into environmental toxicology of nanomaterials remains uncertain, some research reveals the risk of potential negative impacts (Lockman, 2004; Oberdorster, 2005). These residues due to their size can be very dangerous since they can easily be dispersed in air, dilute in water and thus easily come into contact with animal and plant species causing effects so far not well established. In addition, since a significant part of nanomaterials currently correspond to synthetic materials and not available in nature, the ecosystem probably does not possess the physical, chemical or biological mechanisms for its proper degradation. Studies of the impact of C60 fullerenes in aquatic environments have reported oxidative stress in fish exposed to these materials; oxidative stress is an important measure in the impact on living organisms of the ecosystem as it reflects an imbalance between reactive oxygen species (oxidants) and the ability of a biological system to rapidly decontaminate the intermediate reactants or repair the resulting damage (Oberdorster 2004). Other studies report effects of lung inflammation in mammals exposed by inhalation to ultrafine particles of nanoparticles and carbon nanotubes. An additional factor of the potential toxicological effects of carbon nanotubes is their residual content of metals (involved in their synthesis process), which in some cases can reach values as high as 27% by weight, although in general is below 1% (Lam, 2004). This differentiation in the compositions of carbon nanotubes would indicate that although the toxicological effects between them may be similar, the magnitude of its toxicity should be evaluated on a case-by-case basis (Demirel 2015; Rocha, 2015).

Nanotechnology and nanomaterials are making a decisive contribution to improving existing applications or establishing new applications in many sectors of industry (computing, energy, environmental sciences, medicine, food safety and transportation, among others). In addition to transport facilities built with lighter materials (carbon nanotube reinforced plastics, new alloys, etc.) which consume less fuel, nanotechnology could have a major impact on clean energy production. Research is under way to use nanomaterials for purposes including solar cells, fuel cells and more efficient batteries. As important aspects as the supply of drinking water from contaminated sources can have a fundamental impact on the welfare of a large part of the world population.

Specifically in the field of solar cells the contribution of nanotechnology is evidenced in the generation of materials with conversion efficiencies of solar energy to electric energy above current values, which are in the order of 15-20%. It starts from the application of structures that resemble nanowires with more economical and efficient materials than the current technology based essentially on conventional silicon wafers (Tian, 2007). A further example of ecological energy production in which nanotechnology could make important contributions is the area of hydrogen fuel cells, particularly in the development of high surface area catalytic supports and membranes, which should provide greater thermal resistance, mechanical and chemical properties to nanoscale particles of noble metals with diameters ranging from 1-5 nm and which act as active material in the chemical reaction. Another contribution is in materials for the storage of hydrogen, which must have a large number of small pores of nanometric size. In terms of efficient energy storage new nanometer materials for batteries with higher storage capacities and higher load transfer speeds may be the solution for mobile equipment with high energy demand (Alaviitala and Mattila 2015).

Another area of application that has generated great expectations is the supply of drinking water applying the principles of nanotechnology through the development of sensors and equipment for the rapid and low cost detection of impurities, and the development of filtration and purification equipment more efficient and economical. Nanostructured filters have been reported that can remove bacteria and viruses from contaminated water, deionization methods that employ electrodes with high energy efficiencies, removal of contaminants such as arsenic and carbon tetrachloride using magnetic nanoparticles. Eventually nanoparticles could be used to remove industrial pollutants in groundwater (in situ) through chemical reactions (Hillie and Hlophe, 2007). In the same way sensors based on nanomaterials would be able to detect, identify and perhaps neutralize harmful chemicals or biological agents in air and soil with a much greater sensitivity than is possible today (Oyelami and Semple, 2015). Researchers around the world are focusing their efforts on making carbon nanotubes scrubbers and membranes to separate carbon dioxide from the exhaust gases from power plants. In addition, scientists are investigating the particles as self-assembled monolayers on mesoporous supports, dendrimers and carbon nanotubes to determine how to apply their chemical and physical properties for various types of pollution remediation.

Impact on Legislation: The effectiveness of any legislation to regulate chemicals is based on a solid knowledge of the material to be regulated, unfortunately in the case of nanomaterials there is considerable uncertainty about the potential risks of the same, mainly due to the absence of appropriate tests to determine such risks (Justo-Hanani and Dayan, 2014). In the face of limited information on toxicity and exposure, some regulatory and control bodies have implemented preventive legislation (UK, Norway and Australia, among others) recommending to industries that produce, handle or trade nanomaterials or products containing nanomaterials to reduce the use of these materials to the minimum possible, or in the best case scenario to use them, until proper characterization is completed. Despite the lack of knowledge, specific regulations have not been developed on procedures for the characterization of risks and hazards to health and the effects on the environment, some authors have identified three fundamental challenges in the process of generating regulations to regulate nanomaterials: (1) to obtain a consensus on the definition of a nanomaterial, (2) to determine whether it is possible to adapt existing legislation or to develop a new regulatory framework and (3) to define whether nanomaterials should be considered as a different material to its macroscopic counterpart of the same molecular structure (Chaundry, 2006).

Regarding the first challenge, in Europe, the entity responsible for registration, evaluation, authorization and restriction of chemicals REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) defines nanomaterial as an insoluble or biopersistent material, intentionally manufactured with one or more of its external dimensions (or incorporated in its internal structure) in the scale of 1 to 100 nm (Monica 2008). In the US, the national initiative for nanotechnology shares the same definition proposed by REACH, however, it includes nanomaterials present in nature in addition to intentionally manufactured materials. Entities such the American Chemical Society (ACS) and ISO have their own definitions, which sometimes conflict and stress the need to obtain a consensus on the definition that allows to generate appropriate and effective regulation (Boxall, 2008).

The second challenge to be solved is whether the existing regulation can be adapted to the unique characteristics of nanomaterials; a large number of regulators have adopted an incremental approach under the assumption that current regulations for chemicals can be adapted, and in some specific cases, modified to include nanomaterials. However, some authors argue that the special characteristics of nanomaterials demand the generation of new and specific regulations for them. One of the possible complications that may arise from the use of this incremental approach is the constant implementation and / or adaptation of regulatory additions, which could make its application cumbersome and confusing.

The third challenge is to define whether the physicochemical and toxicological characteristics of nanomaterials are equivalent to those of the material with the same chemical composition in the scale outside the definition of nanomaterial, which would have a fundamental impact on the requirements demanded of the producers before their commercialization (Chaundry, Blackburn, 2006). In U.S.A. if a nanomaterial is classified as a substance other than its macroscopic counterpart of the same molecular structure would require under the current regulations that the producer generates a prefabrication note (PMN) which must be sent to the EPA before the producer can produce any quantity of material for purposes other than research and development; This prefabrication note should include information on environmental impact and toxicity, among others (Hansen et al. 2008; Hansen, 2008). On the other hand the European community has decided to assume that nanomaterials are covered by the definition of chemical substances under REACH regulation with the provision that "when an existing chemical that is already marketed in bulk and is introduced into the market in the form of nanomaterial, the registration format will have to be modified to include the specific characteristics of the substance as nanomaterial." (Hansen and Tickner, 2008)

A new regulatory framework should be based on fundamental principles such as protection of health and the environment, innovation and a high level of participation of the different public and private entities involved (research and development centers, producers, consumers, regulators, etc.). In order to ensure the protection of health and the environment, in the results of toxicological tests, at least information on physico-chemical characteristics, degradation and bio-accumulation must be required; as well as recommendations regarding occupational and environmental exposure and the need to make the manufacturers responsible for their nanomaterial and / or product throughout the product life cycle (Warheit, 2004; Hansen and Tickner, 2008; Zea, 2012). It is essential to obtain up-to-date information on the nature and extent of current and future sources of nanomaterials in the environment and to determine the interaction mechanisms of nanomaterials during their life cycle from the time of their manufacture to their final disposal; likewise, there is a need to develop standardized methods for detecting and quantifying the amount of nanomaterials in various environments (air, sea and groundwater, soils, etc.), and critically accounting for changes in behavior within their dispersion media (Warheit and Laurence, 2004).

2. CONCLUSIONS

The historical trend shows that countries that have invested in the research and development of new technologies, reflect their effort in the revenue they generate; there is a leadership of countries such as the United States and member countries of the European community around the creation of numerous research centers that are generally integrated with the research and development efforts of universities and companies. Other countries that have clear policies to encourage nanotechnology are Australia, Japan, South Korea, India, China and Israel through plans and investments specifically for nanotechnology research and development.

In terms of the effects of nanomaterials on health it is clear that nanomaterials have the ability to traverse most of the protective membranes of the body and accumulate in various organs. The mechanism of exposure most studied is inhalation, while the effects by skin contact and ingestion have not had the same coverage. The general effects can range from simple irritation to tumor formation and molecular modification of DNA.

Public assessment and debate on the effects of nanotechnology and nanomaterials on the environment is an important topic of discussion in multilateral forums such as the United Nations (UN) and in European countries, the United States and Japan, where research groups with specific objectives have already been established for the determination, evaluation and analysis of these effects. While research into environmental toxicology of nanomaterials remains loaded with uncertainty, some research reveals the risk of potential negative impacts. It is important to note that developments in nanomaterials and nanotechnology are also potential solutions to current environmental problems, especially in areas of great impact such as the supply of drinking water, contributing to the development of sensors and equipment for rapid and low cost detection of impurities, filtration and purification equipment.

The future of nanotechnology is a completely unknown territory. It is almost impossible to predict, unlike other technological revolutions, nanotechnology and nanomaterials arrive at a time when social and environmental awareness play a large role in daily discussions, making necessary for their development to go hand in hand with proper use of natural resources, simultaneously determining their social, political and economic effects.

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