Researching Risks of Nanomaterials in Mexico

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Abstract: The aim of this article is to evaluate, using available direct and secondary data, the risks to human health and the environment within nanotechnologies research in Mexico. The argument is advanced in four sections. The first illustrates the implications of the risks posed by nanoparticles and nanomaterials to workers, consumers, and the environment. Next, to provide context, is a review of the state of nanotechnologies development in Mexico. This is followed by an outline of the methodology employed, where two protocols were used: The first entailed the creation of a database containing all articles on nanotechnologies published by Mexican authors over a 12-year period and then searching for key terms associated to the risks of nanomaterials; the second protocol involved a web-based search to identify all researchers working in this area. Finally, the results are presented with the conclusion that the subject of risks is, essentially, absent from nanotechnologies research in Mexico. **DOI: 10.1061/(ASCE)HZ.2153-5515.0000247.** *© 2014 American Society of Civil Engineers.*

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Introduction

After Brazil, Mexico is the second country advancing nanotechnologies research and development (R&D) in Latin America (Robles-Belmont 2012; Kay and Shapira 2009; OICTeI 2008). From this point onward, this paper will use the term "nanotechnologies" to group both nanosciences and nanotechnologies. A review of bibliometric data reveals that Mexico has published close to 4,500 scientific articles on nanotechnologies in the 2000–2012 period. In addition, as reported by the National Institute of Statistics and Geography (INEGI), with data from a recent survey, there are up to 188 companies working with nano or doing research on this technology in the country.

At the beginning of the present century, the Mexican government endorsed the development of nanotechnologies as strategic technologies to achieve an increase in economic competitiveness. For this reason, the government created the National Nanoscience and Nanotechnology Research Network, built two national laboratories, and promoted the creation of industrial parks specializing in nanotechnologies. However, there is no institution monitoring the evolution of nanotechnologies to identify priority areas of research, the amount of resources employed or required, and other relevant information. Neither is there a regulatory framework to supervise research and the commercialization of products containing nanomaterials.

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The purpose of this article is to evaluate, using available direct and secondary data, the relevance of the risks to human health and the environment within nanotechnologies research in Mexico. To this purpose the authors gathered bibliometric data and analyzed information from the main websites of public and private research centers. The data showed that the subject of risks is, essentially, absent within nanotechnologies research in Mexico.

The article is organized in four sections. The first illustrates the implications of the risks of nanoparticles and nanomaterials to workers, consumers, and the environment. The second examines the state of nanotechnologies development in Mexico. In the next section the methodology is described in detail, and in the fourth the data and the final results are presented. At the end, a brief set of conclusions is provided.

Nanotechnologies and Risks to Consumers, Workers, and the Environment

There is a wide array of empirical evidence to support calls for the implementation of a precautionary approach in the creation of products containing nanomaterials or with nanotechnological elements. Firstly, it is known that these technologies develop, at the nanometric scale, physical, chemical, and biological properties different from the ones typically presented. In addition, the size of nanomaterials allows them to pass through biological barriers and to have great mobility within the human body. Second, the interaction of nanomaterials with living organisms may have outcomes not anticipated by science. On one hand, most nanomaterials and nanostructures enter the market with no previous toxicity-testing; on the other, most of the tests that are applied are not suitable for an evaluation of the toxicity of nano-structures. Third, several studies in-vitro and conducted in animals showed that certain nanomaterials are toxic and, most likely, are toxic to humans as well (Kulinowski 2009).

There are dozens of specific studies that raise concerns about nanoparticles and nanomaterials. Consumers could be exposed to nanomaterials through ingestion, inhalation, or direct contact. This could happen by using or consuming products with nanomaterials; by nanomaterials having been released into the air or the environment; or as a result of garbage decay, accidents, or

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the burning of products, as a result of which nanomaterials and nanoparticles could be reabsorbed by food and other products (Kohler et al. 2008).

Carbon nanotubes, in several early studies, showed toxic patterns similar to asbestos, causing allergies and developing carcinogenic properties (Poland et al. 2008; Takagi et al. 2008; Chou et al. 2008; Ghafari et al. 2008; Nygaard et al. 2009). Other nanomaterials, already in use in the food processing and packaging industry, can have serious implications to health and the environment. Some reports have concluded that nano-silver particles used as bactericides can harm DNA chains, interfere with DNA replication, and even bind with DNA (Yang et al. 2009). The same manufactured nanomaterial (nano-silver) can damage epithelial cells (Stoehr et al. 2011) and may have destructive environmental effects (Liu et al. 2012). The Sweden Chemical Agency, in response to a request from the Stockholm Agency of Potable Water, showed that nanoparticles in textiles are released after a number of laundry cycles and after being in contact with certain kinds of soap (Sweden Chemical Agency 2012).

Some other studies illustrate how silver and silica nanomaterials employed in food packaging migrate to the actual food (Avella et al. 2005; Dekkers et al. 2010; Huang et al. 2011). It is worth mentioning that an excess of silver in the human body causes argyrosis (a pathologic bluish-black pigmentation in a tissue resulting from the deposition of an insoluble albuminate of silver), and there are studies showing the effects of nano-silver in this regard (Liu et al. 2012). In the food sector there are other nanomaterials currently in use such as titanium dioxide. Zhu et al. (2010) show how titanium dioxide nanoparticles move within the food chain.

There is little research on the impact of waste that contains nanomaterials. The topic of waste management in laboratories, especially nanomaterials, is a grey area, and it remains uncertain whether laboratories consider these materials as toxic. In addition, there is not enough information to conclude whether management protocols for hospital debris and research laboratories are sufficiently robust to safely degrade nanomaterials.

Apart from the above-mentioned studies, there are other concrete cases of workers affected by nanomaterials. Workers are the social group most exposed to the risks of nanomaterials. At the end of 2013, an article was published based on a comparative study of 14 factories in Taiwan that followed key biomarkers on 124 workers who handled nanomaterials on the front line over a six-month period, and a control group of 77 who did not. The results showed that across the three body areas analyzed (lungs, cardiovascular effects, and antioxidant enzymes), the workers who handled nanomaterials showed comparative values of lowered efficiency/decreased performance versus those who did not. This does not mean that the manipulation of nanomaterials resulted in harm to the point of illness, but at the very least, this example showed that the inadvertent transfer of nanomaterials most likely had some effect on the human organism (Liao et al. 2013). The unfortunate case of seven Chinese workers in a paint factory who worked with nanotechnologies should not be forgotten. After a period of between 5 and 13 months of work they were hospitalized with respiratory problems; two of them died and the other five were left with permanent injuries (Song et al. 2009). In another study on 277 workers handling nanomaterials and a control group of 137 workers that did not handle nanomaterials, the researchers found a breakdown in the antioxidant enzymes and an increment in the biomarkers of cardiovascular expression in the first group of workers (Liou et al. 2012). These examples provide strong evidence supporting the calls of workers' unions for the application of the precautionary approach.

Development of Nanotechnologies in Mexico

In Latin America, Mexico is second only to Brazil in the development of nanotechnologies (Foladori and Invernizzi 2013). Although nanotechnologies development is just beginning in Mexico, and is primarily oriented toward basic research, a previous study identified more than 100 businesses that offer nanotechnologies products for sale, whether they be domestically produced or imported (Záyago et al. 2012). More recently, with data from a survey, the National Institute of Statistics and Geography (INEGI) estimated the possible existence of 188 enterprises using (i.e., research/manufacturing) nanotechnologies (INEGI and CONACYT 2013). In addition, there are more than 60 universities and research centers endorsing research projects associated with nanotechnologies, and at the same time, there are several international collaborative agreements currently in effect (Robles-Belmont 2012; Záyago and Foladori 2010; Záyago Lau et al. 2014).

Mexico has roughly two decades of research experience in nanotechnologies. The government has taken measures to make these technologies part of a strategic plan to advance technological competitiveness in the country and has provided financial support for the creation of national laboratories, a network of researchers, and specialized industrial parks (Záyago and Foladori 2010). It has not, however, formed a national coordinating body to establish objectives and a set of norms to direct its development.

As a consequence of the negative impacts of the development of nanotechnologies, especially the ones associated with the risks to health and the environment (Kulinowski 2009), several countries have implemented regulatory measures [see understandingnano.com/regulation 2014 for more information (Understandingnano.com)]. In Mexico there have been some initial steps toward the regulation of nanomaterials. By the end of 2012, a commission coordinated by the Metrology Center of the Secretary of Energy (CENAM) released a document with general guidelines to regulate nanotechnologies (Grupo de trabajo sobre regulaciones para la nanotecnología 2012); but these guidelines are intended to homogenize commercial standards, and have little to do with the evaluation and regulation of risks (Foladori and Záyago Lau 2014). The next section illustrates the state of nano-research related to the risks to human health and/or the environment in Mexico.

Methodology

Two protocols were used to gather data on the attention that Mexican researchers are assigning to issues of risks to health or the environment of nanomaterials.

The first protocol used a database containing all articles on nanotechnologies published by Mexican authors (using tracking terms identified by Kostoff et al. 2006) for the 2000 to 2012 period (Záyago Lau et al. 2014). There were 4,471 articles published with at least one author with an institutional affiliation in Mexico at the moment the article was published. Then, key terms were identified that are associated with toxicity and risk analysis of nanomaterials in key literature on the topic. The terms were toxic, dysfunction, impair, oxidative stress, inflammation, exposure, risk, harmful, hazard, oral uptake, ingestion, skin penetration, inhalation, transdermal/trans-dermal. Next, those terms were tested by doing a search within all articles. The manual revision identified—and discarded—those articles that did not have a direct relation to the topic such as the ones related to how nanotechnologies could be used to repair the environment and/or use it as medicine, pharmacological vehicle, or implant; thus leaving only those articles that dealt with the potential risks of nanomaterials or nanoparticles to human health and/or the environment. Finally, a search was

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performed for the following four key terms: toxic, dysfunction, impair, and oxidative stress, which directly identified articles related to risks of nanomaterials to health or the environment.

The second protocol focused on the identification, within all the institutions that are doing nanotechnologies related research in Mexico, of research groups, laboratories, or individual scientists researching risks of nanomaterials. To this end, the academic clusters (AC; *Cuerpos Académicos* in Spanish) database of the Ministry of Public Education (SEP) that is part of the Program for Professorship Development (PROMEP) were used first. The PROMEP was created to improve the research competence and scientific capabilities of the faculty attached to public universities, polytechnic universities, and technological institutes. PROMEP endorses the formation of research groups, or AC. Each AC is organized around a common research interest with the objective of generating new knowledge in the area. In addition, each AC is required to have at least three members, and the program allocates resources to execute research plans, publish findings, or encourage academic mobility [Programa de Mejoramiento al Profesorado (PROMEP) 2013]. The AC program's search engine was used (http://promep.sep.gob.mx/ca1/) with the key word nano*. Out of the 4,087 AC as of March 2013, 99 were found with research interests on nanotechnologies. Afterward, a search was conducted within the 99 AC to determine which ones were actually assessing risks of nanomaterials. The key terms described in the section above were used and the same technique to identify the AC looking at the topic of interest. In addition, explorations included each university, research center of the National Science and Technology Council (CONACYT), and private institution that had research activities on nano but that are not part of SEP's AC program. To increase the reliability of the methodology the same key words were used on a case-by-case search, using the institution's web search engine.

Research on the Toxicity of Nanomaterials in Mexico

From the 4,471 articles found, only 25 dealt with the toxicity of nanomaterials to human health or the environment. This represents 0.6% of the total for the 12-year period. As a way of comparison: the articles on the topic of nanomedicine numbered 182, which represent 4.1% of the total (author's ongoing research). The distribution of the articles on the toxicity of nanomaterials by institution is shown in Table 1.

The individual search within the main research institutions delivered similar results. Out of the 99 AC in PROMEP's database doing nano-associated research, only one (UDG-CA-682), located at the University of Guadalajara, is doing research on the risks of nanomaterials, specifically on the cytotoxicity of nanomaterials (PROMEP 2014). Two of the CONACYT Centers, not included in the PROMEP database, are performing research on the toxicity of nanomaterials. One is the Potosí Institute of Scientific and Technological Research (IPICyT), and the other is the CIMAV (Centro de Investigación en Materiales Avanzados, S.C.), which in 2011, in partnership with the National Ecology Institute (INECOL), planned to create a laboratory to analyze the effects of nanomaterials on the environment, as well as their biocompatibility [Centro de Investigaciones en Materiales Avanzados (CIMAV) 2011]. However, the laboratory is no longer in operation. Other research centers were found at National Autonomous University of Mexico (UNAM), Advanced Materials Research Center of the National Polytechnic Institute (CINVESTAV), some public research centers, and some private universities. However, the total number of research centers managing projects on the potential risks to health or the environment of nanomaterials is no more than 10. The results are summarized in Table 2.

Table 1. Articles on Risks of Manufactured Nanomaterials with At Least One Author from a Mexican Institution Published in the Web of Science (WoS) 2000–2012 and by Institution

Institution	Total	%
Total on nanotechnologies	4,471	100
Toxicity of manufactured nanomaterials	25	0.6
Autonomous University of San Luis Potosí (UASLP)	5	—
Guanajuato University (UGTO)	4	—
• National Autonomous University of Mexico (UNAM)	3	—
• Metropolitan Autonomous University (UAM-I, UAM-C, UAM-A)		
• Advanced Materials Research Center (CIMAV)	2	—
• Advanced Studies Research Center (CINVESTAV)		
• National Cardiology Institute–Ignacio Chávez (INC- IC)		
• Potosí Institute of Scientific and Technological Research (IPICyT)		
• Sonora University (UNISON)	2	—
• Autonomous University of the State of Mexico (UAEM)		

In addition to these institutions, that have or have had projects related to the risks associated with nanomaterials, the CENAM (the National Metrology Center), a suboffice of the Ministry of Economy, has (as one of its objectives) to register any nanomaterial with potential risks to human health in the country or about to enter the country (Lazos-Martínez 2014). Unfortunately there are no records of nanomaterials or serious advances in this project.

The result is that institutions undertaking the research of risks of nanomaterials are highly scattered. This scenario puts Mexico in a weak position in the face of the rapid introduction of new products containing nanomaterials to the market. It is worth noting that there is no official database of nano-products in the Mexican market. However, there are developments that may indicate some trends. For instance, the number of nano-products in the inventory of the Woodrow Wilson Center reaches 1900 (WWICS 2014); but it does not register nanomaterials, which could increase this figure exponentially. Mexico is the country with the most free trade agreements signed in the world and as a member of the North American Free Trade Agreement (NAFTA—with the United States and Canada as partners), it is very likely that nanotechnologies products could enter the country in any given time. In addition, the commercialization of other intermediate products such as single-walled carbon nanotubes, which can reach up to several thousand tons traded each year in the world (World Health Organization 2013), must be acknowledged. This illustrates the amount of nanomaterials that are currently traded worldwide and raises concerns as to how much of this material could be arriving in Mexico today. In fact, many of the nanomaterials used in Mexican laboratories are imported from the United States, and some others, such as nano-silver, are manufactured locally. Sigma Aldrich, for instance, a life science and high technology transnational company is one the main suppliers of nanomaterials to many Mexican research centers and laboratories (Sigma-Aldrich 2014).

Nano-pollution hot spots in Mexico may be located at the cities where specialized parks in nanotechnology R&D are established. The city of Monterrey may be the most important example. The Mexican Nanotechnology Cluster is located in this city, and this park is the flagship project of nanotechnology development of the Mexican Government (Zayago 2011). Most of the 40+ enterprises located at this cluster manufacture and handle nanomaterials to

Table 2. Institutions with Research Projects on the Risks of Nanomaterials According to Institutional Webpages

Institution	Topic	Reference
Guadalajara University (UdeG)	Cytotoxicity of nanomaterials Academic Body (UDG-CA-682)	PROMEP (2014)
Potosí Institute of Scientific and Technological Research (IPICyT)	Toxicity and biocompatibility of nanomaterials	IPICyT (2013)
Advanced Materials Research Center (CIMAV) and National Ecology Institute (INECOL)	Laboratory on effects of nanoparticles in the environment; biocompatibility (in preparation)	CIMAV (2011)
Materials Research Institute – UNAM (IIM)	Toxicity of nanomaterials and their effects in medical, cosmetic and electronic device applications	El Universal (2013)
Center for Applied Sciences and Technological Development/ Chemistry Faculty (UNAM)	Phytotoxic effects of carbon nanomaterials	CCADET-UNAM (2011)
Centre for Genome Science (CCG-UNAM)	Eco-toxicity of carbon nanomaterials	CCG-UNAM (2014)
Advanced Materials Research Center of the National Polytechnic Institute (CINVESTAV)	Research line on the impact of nanomaterials and potential toxicity	CINVESTAV (2012)
Center for Research in Applied Science and Advanced Technology (CICATA-Qro)	Synthesis of polymernanotransporters of silver nanoparticles. Evaluation of their toxic effect on neoplasm cellular cultures.	Casañas-Pimentel et al. (2008)
Autonomous University of Nuevo León	Biotechnology and Nanotoxicology Research Center	UANL (2012)
Monterrey Technological Institute of Higher Studies (ITESM)	Risks of nanomaterials to human and environmental health	Salazar (2013)
University of the Americas in Puebla (UDLAP)	Nanotoxicology in food and medicine	UDLAP (2014)
Autonomous Popular University of the State of Puebla (UPAEP)	Biocompatibility of nanomaterials and their toxicity in medical applications	UPAEP (2014)

Note: February 2014 search.

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supply the chemical sector (Zayago 2011). Nevertheless, further research is required.

Another concern regarding the management of the risks of nanomaterials is the lack of regulation in Mexico. The matter of risk, however, is at the core of most nano-product regulatory policy worldwide. Europe has implemented regulation frameworks for cosmetics, foods, and biocides based on the precautionary and the "no data, no market" principle. The United States has a different approach, based on "known risks." This implies that no regulation is to be implemented before any risk is proven scientifically. Another principle currently active in the United States is the "presumption of safeness principle," which assumes that a product is safe unless risks are proven. Under this framework, the United States only requires a simple notification before trading cosmetics, foods, and biocides with nanomaterials. In this context, the United States is negotiating with its trading partners a platform to homogenize the regulation of several commercial products, including nanotechnologies-based goods. In fact, the United States has influenced the Mexican government to adopt its regulatory framework for nano-products (Foladori and Zayago-Lau 2014). The lack of research groups specialized in risk analysis in Mexico is another matter of concern, resulting from a lack of interest from academic and research institutions.

Conclusions

The topic of risks to health and/or the environment from manufactured nanomaterials has been absent from the vast majority of research efforts in Mexico, as the bibliometric analysis shows. Only 25 scientific articles dealt with this issue out of the more than 4,000 articles on nanotechnologies published in the past 12 years. This represents only 0.6% of the total. Also, a manual search by a research center did not offer many results. There are very few projects led by interested individuals on this subject. However, this preliminary study illustrated the absence of research groups created by institutions to pursue the study of risks in products containing nanomaterials. There are no institutions making this topic a goal and a long-term commitment for their research groups. The risks of manufactured nanomaterials, as a research topic, are not of interest to most researchers and institutions in Mexico. This echoes the fact that CONACYT, in charge of funding most scientific research in the country, does not have a mandatory policy to raise the funding recipient's interest to look at the potential risks to health and the environment of nanomaterials. Neither does the National Nanoscience and Nanotechnology Research Network, which encompasses a great number of researchers looking at nanotechnologies, have any opinion in the matter. And without a regulatory framework to research risks, the topic is absolutely off of the research agenda in Mexico.

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