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POSITION PAPER

Nanoparticle pollution and associated increasing potential risks on environment and human health: a case study of China

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Abstract The aims of this study are (1) to discuss the mechanism of nanoparticle lifecycle and estimate the impacts of its associated pollution on environment and human health; and (2) to provide recommendation to policy makers on how to leverage nanopollution and human health along with the rapid development of economics in China. Manufactured nanoparticles (MNPs) could either directly or indirectly impair human health and the environment. Exposures to MNP include many ways, such as via inhalation, ingestion, direct contact, or the use of consumer products over the lifecycle of the product. In China, the number of people exposed to MNP has been increasing year by year. To better provide medical care to people exposed to MNP, the Chinese government has established many disease control and prevention centers over China. However, the existing facilities and resources for controlling MNP are still not enough considering the number of people impacted by MNP and the number of ordinary workers in the MNP related industry applying for their occupational identification through the Center for Disease Control and Prevention. China should assess the apparent risk environment and human health being exposed to MNP and develop action plans to reduce the possibility of direct contacts between human beings and the emerging nanomaterials. In addition, we suggest more comprehensive studies on the MNP behavior and the development of quantitative approaches to measure MNP transport, and persistence should be carried out.

Keywords Nanoparticle · $PM_{2.5}$ · Human health · Environmental health · Nanopollution

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Introduction

Nanotechnology and nanomaterial development are experiencing unprecedented expansion in the 21st century. Nanoparticle pollution is also called by “invisible pollution” and considered as the most difficult pollution being managed and controlled. Long-term exposure to nanoparticles may cause serious damage to the human’s respiratory tract, lung diseases, heart diseases, and premature death (Pui et al. 2014). However, many emerging novelties of nanomaterials would expedite the rising of potential risks to industrial workers, consumers, and the environment. In present, there are no more reports on the clinical toxicity to human and occupational diagnosis due to the long-term exposure to nanoparticles in China.

It has been reported that a worker from Henan Province in China, who is employed at a metal materials company, suffered from severe illness and allergy after being exposed to nanoparticle for an extended period of time. Due to a lack of complete standard diagnosis and regulation, the local medical department refused to admit that an occupational hazard existed. The worker had to go to the hospital by himself to determine whether his lungs had suffered from exposure to nanoparticle pollution by opening his thoracic cavity (Sina

2009). The worker sued the medical department and eventually won the lawsuit, which had drawn the attention of the Chinese government to prompt legislation related to nanoparticle diagnosis. Another example involved seven women who developed lung problems and became ill after working in a paint factory in China. Two of the seven workers died (Song et al. 2009) even after emergent treatment. These reported illnesses and casualties reveal the fact that the potential occupational and public exposures to manufactured nanoparticles (MNPs) could bring high health risk to humans. Therefore, standardized training procedure and risk management plan for the benefits of workers who will potentially be exposed to nanoparticles for a prolonged period of time need to be established in China, as well as in other developing countries.

Therefore, the objectives of this study are to (1) comprehensively understand the nanoparticle source and its lifecycle, (2) describe the human body's reactions after being exposed to nanoparticle pollution by different pathways, and (3) introduce the nanopollution development and its associated pollution impacts in China, especially the $PM_{2.5}$ pollution. We hope the findings of this study could provide insights and recommendations of how to cope with nanopollution and associated potential health risks in China and elsewhere in the world.

Methods

The data in this manuscript on nanomaterial consumption in China between 2000 and 2010 are obtained from the Chinese Nanomaterials Industry Market and Investment Forecast Report (2011–2017) (NNCP 2010; MIIT 2011). The main diseases proportion related with nanopollution are retrieved from Center for Statistic Information Ministry of Health (2005–2011) (CSIMH 2011). The change of prevalence, hospitalization rate, and mortality due to $PM_{2.5}$ and the respiratory and cardiovascular diseases mortality in major cities are from Chinese Center for Disease Control and Prevention (CSIMH 2011; CNEMC 2013). The $PM_{2.5}$ monitored data and their composition proportions in four major cities in China are collected from Huang et al. (2014), and $PM_{2.5}$ distribution are from NASA, USA.

Nanoparticle source and its lifecycle

Nanoparticle source

The nanoparticles (i.e., <100 nm) are invisible to the human eyes and are of similar size to some biological entities (Sweet and Strohm 2006). The source of nanoparticles can be anthropogenic or natural and can exist with a wide range of morphologies, including dendritic structures, spheres, platelets, tubes, flakes, and rods (Sweet and Strohm 2006; Dhawan and Sharma 2010). Natural nanoparticle widely exists in environment, such as airborne nanocrystals of sea salts, biogenic magnetite, carbon nanotubes, fullerenes, etc. (Buffle 2006; Nowack and Bucheli 2007), and soils also contain different kinds of organic and inorganic nanoparticles, such as humic substances, clay minerals, hydroxides and metal oxides, and imogolite and allophone (Theng and Yuan 2008; Miao et al. 2010, 2011). The anthropogenic sources of exposure to MNPs mainly include soot exhaust, furnaces, power plants, pigments from paint and toner, welding fumes, construction sites, etc. MNPs can be further categorized into two groups: incidental, which are nanoparticles produced unintentionally in manmade processes (e.g., carbon nanotubes, platinum- and rhodium-containing nanoparticles from combustion byproducts, carbon black, and fullerenes), and engineered or manufactured, which are nanoparticles produced intentionally due to their nanocharacterization (Nowack and Bucheli 2007; Dhawan and Sharma 2010). MNPs take the most important proportion in nanoparticle constitution and do not exist as a uniform group of substances because they are different in sizes, surface areas, shapes, bio-persistence, environments, and chemical compositions, including cadmium, iron, cobalt, silver, copper, platinum, silicon, gold, titanium dioxide, zinc, and others (Dhawan and Sharma 2010). According to Sweet and Strohm (2006), the new and unique properties of MNPs mentioned above will result in different environmental behaviors that could bring unforeseen or unintended risks.

MNP materials have shown broad functionality and applicability in a large number of industrial and consumer applications, including water treatment, energy production, novel therapeutic drug delivery systems, home appliances, consumer electronics, dietary and supplements, and sports equipment. With rapid advances in nanotechnology, many products containing engineered MNPs have produced and gained popularity in the market, such as scratch-free paint, sports equipment, electronic components, sun creams, wrinkle- and stain-resistant fabrics, medical products, etc. (Groso et al. 2010). MNPs are used in sunscreens and cosmetics due to their transparent appearance and enhanced efficacy. MNPs are also extensively used in tennis rackets and baseball bats to improve their strength and make them lighter. Textile industries also use nanotechnology to produce stain-, wrinkle-, and water-resistant clothing (Thomas et al. 2006). Inorganic metal or metallic oxide nanomaterials in particular focus on three products, including paints, food packaging, and fuel additives (O'Brien and Cummins 2011). Silver nanoparticles are being used in washing machines as antibacterial agents; cadmium nanoparticles are being explored for the development of efficient, low-cost solar panels; nanoscale iron are being used in water treatment applications to remove contaminants from wastewater; spherical Ti and carbon nanomaterials are being evaluated for their potential to function as novel drug delivery systems based on their affinity for specific cellular organelles;

and ZnO nanoparticles are used in food packaging as well as daily life appliances like washing machines and water purifiers (Linkov et al. 2009).

Under natural environmental conditions, a nano contaminant cannot be directly regarded as a nanomaterial even though it is ranked within the nanoscale in terms of grain size and the sharing of many common characteristics. In most cases, environmental nanopollutants take the form of large macromolecules or colloids. Nanoparticles are found almost everywhere in nature. Examples of natural sources are volcanic ash, water, and soil (Buffle 2006; Nowack and Bucheli 2007; Miao et al. 2015). The natural occurrence of nanoparticles is the consequence of variegated and long-term geobiological processes. Some of these naturally occurring nanoparticles are considered toxic to human health while others are not. A small percentage even exists within living organisms (Theng and Yuan 2008). Globally, the ongoing development of nanotechnology is rapid, and both of the absolute quantity and diversity of MNPs are promptly increasing from time to time.

MNPs lifecycle

The behavior of how MNPs will react in terms of adsorption, accumulation, persistence, aggregation, and mobility in relation to different environmental media will ultimately have an effect on both the magnitude of nanoparticle fallout and the potential increase in human exposure (Dhawan and Sharma 2010). MNPs released into the biosphere can occur once or multiple times throughout the lifecycle of consumer products that contain nanomaterials via normal product use, destruction, recycling, or disposal. Figure 1 shows the main movement of MNP through its typical life cycle (Thomas et al. 2009). Many of the most important health and safety concerns of MNPs are due to lack of knowledge of the health effect, the levels of occupation, the types of exposure to MNPs during the production, the use of MNPs, as well as in applying different MNPs in applications of nanotechnologies for consumers and other products (Savolainen et al. 2010a, b). The wide range of products is also indicative of the range of exposure potential risk. Products such as sunscreens, health supplements, and cosmetics may have great exposure potential because they are ingested or applied directly to the skin. At the other end of the spectrum, exposures to nanomaterials that are used in electronic devices and sports equipment are expected to be trivial because, in these products, the nanomaterials are incorporated into relatively durable matrices. Other products, such as spray products, can directly release particles into the breathing zone and be inhaled by respiration.

Common ways that MNPs can enter the human body is by the ingestion of contaminated drinking water or by the food chain transferring mechanism if MNPs are used in food production processes. Exposures to MNP can occur via inhalation, ingestion, or direct contact, and the use of consumer products over the life cycle of the product (Gottschalk and Nowack 2011; O'Brien and Cummins 2011; Gao et al. 2013). The potential risk also exists via skin adsorption. The workers who engage in MNP-involved manufacturing process would be the first to contact MNPs, and the following individuals would be the workers in occupational settings who characterize the MNPs (e.g., size ranges of discreet particles, agglomeration) and quantify the amount of MNPs (Thomas et al. 2009).

MNPs' health effect by life cycle

Some MNPs have problematic properties that could cause harm to the human health, either directly or indirectly (Baun et al. 2008; Poland et al. 2008). The surface area of MNP is an important factor to determine MNPs' toxicity as the interaction of the MNPs with biological systems takes place on their surfaces (McNeil 2005). Furthermore, MNPs often display good transfer into and across epithelial cells (Tsuji et al. 2006) and then distribute to other body compartments probably as a function of size and surface properties (Thomas et al. 2006). When MNPs get inside of the human body, they come into contact with different biomolecules, especially protein (Bihari et al. 2008; Lynch and Dawson 2008), which lead to altered properties of MNPs, thereby affect their biodistribution and interactions with biostructures and cells. The binding of protein with MNPs can trigger conformational changes in protein folding, altering its biological function, and affecting the signaling pathways activated by MNPs (Bihari et al. 2008; Lynch and Dawson 2008).

Although biotoxicity has been reported for multiple MNPs (Table 1), the exact properties of MNPs and the reasons for their toxicity to humans are poorly understood. Most of MNPs need further confirmation, and it is currently impossible to systematically link reported MNP properties to the observed effects for effective hazard identification. Nowadays, most of the studies related to MNPs' toxicology are preliminary and confined to the classical in vitro toxicity test methods established for drugs and chemicals. However, the methods used in traditional toxicology cannot be applied essentially to MNPs' toxicity assessment as MNPs display several unique physicochemical properties.

The health effects of MNPs are concerned on the effects of these particles on the lungs, genotoxic, and possible carcinogenic effects of MNP (Savolainen et al. 2010b). Mayer et al. (2009) used human blood to determine the effects of size and surface charge of polystyrene MNPs on coagulation induction, thrombocyte, complement, granulocyte activation, as well as on hemolysis. Upon inhalation, surface reactive nanomaterials would be expected to exhibit their principle effects in the lungs (Sweet and Strohm 2006). MNPs would

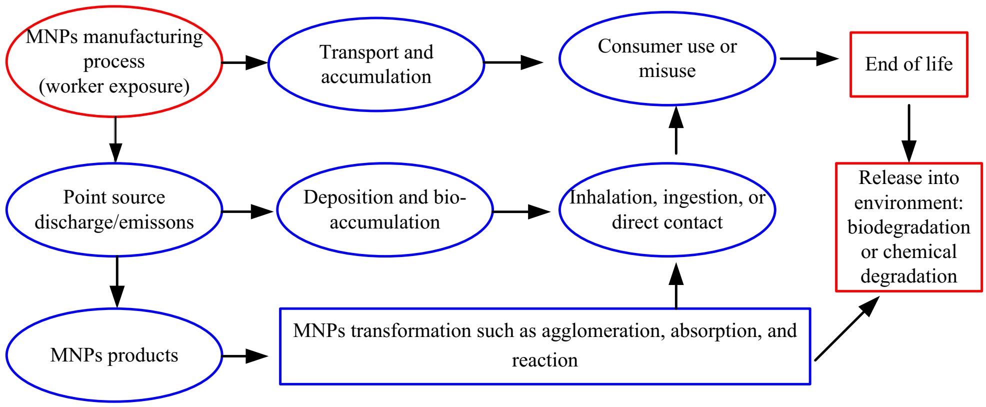

Fig. 1 Potential exposure risk in manufactured nanoparticle (MNP) process through a typical life cycle adapted from Thomas et al. (2009)

induce pulmonary inflammation subsequent to intratracheal installation or intratracheal aspiration of MNPs suspension into the air (Savolainen et al. 2010a). A number of different MNPs show marked cytotoxicity or their genotoxicity, but it still lacks data at this stage (Cunningham 2007). When MNPs were introduced into the abdominal cavity, they induced asbestos like pathogenic changes in the mesothelial lining of the abdominal cavity. Typical changes were increased number of inflammatory cells and protein exudate in the cavity as well as lesions in the mesothelium (Poland et al. 2008).

As a result of lacking enough related MNP risk assessment, it is difficult to evaluate the different aspects of nanotechnology. The definitions of nanotechnology and MNP materials are vital as a clear and accurate definition would eventually help to define the scope of regulation and determine which nanomaterials and its applications are covered and which producers have to comply with regulation. The current lack of tests on the characterization of MNPs makes it impossible to identify causality between observed hazards and specific physical and chemical properties.

Nanoparticle pollution impact on human health in China

Nanoparticle pollution in China

China has become the largest nanomaterial "market" in Pacific Asia due to the rapid economic development (MIIT 2011; Gao et al. 2013). The "World Market for Nanotechnology and Nanomaterials in Consumer Products" estimated that nanotechnology and nanomaterial revenues in consumer products were approximately 1,545,000 USD in 2009 (NNCP 2010), and this is expected to increase to 5,335,000 USD by 2015 (MIIT 2011). Growth is primarily driven by a rising demand for consumer electronics and household cleaning products. Nanomaterial consumer markets in China have undergone rapid growth in the past decade. This market approached ten billion CNY (Fig. 2). From 2000 to 2010, the total amount of MNPs discharged through wastewater exceeded 225×10^5 t year^{-1}, and the total amount of MNP emission by dust reached up to 10 t year^{-1} (Gao et al. 2013). Industrial sources were the primary contributors to MNP dust deposition.

$PM_{2.5}$ pollution in China

$PM_{2.5}$ indicates particulate matter with an aerodynamic diameter of less than 2.5 μm which is important composition of nanoparticle and closely relate with human health. $PM_{2.5}$ differ not only in composition but also in terms of characteristics such as solubility, persistence in the atmosphere, reactivity, biological properties (toxicity and carcinogenicity), chemical structure, and elemental composition; the toxicity of $PM_{2.5}$ fraction depends on the emission sources and the aerodynamic diameter of the particles (Kim and Jaques 2000; Hernández-Mena et al. 2011).

China experienced extremely severe and persistent haze pollution (Fig. 3a). According to CNEMC (2013), the daily average concentrations of $PM_{2.5}$ in 74 major cities in China has exceeded the Chinese pollution standard with 75 μg m^{-3} and is twice of the EPA standard with 35 μg m^{-3}. This severe pollution is accompanied by extremely poor visibility and degradation of air quality. The poor air quality leads to a sharp increase in respiratory diseases. Based on Huang et al. (2014), we find out that the daily average $PM_{2.5}$ concentration at Xi'an is 345 μg m^{-3}, which is more than twice of the other sites. Followed by Xi'an, the daily average $PM_{2.5}$ for Beijing, Shanghai, and Guangzhou are 159, 91 and 69 μg m^{-3}, respectively (Fig. 3b, c). The magnitude of daily average $PM_{2.5}$ for those cities are approximately one to two orders higher than that of the main cities in the US and European countries. As Fig. 3c shows, the relative contribution of primary particulate emissions to $PM_{2.5}$, including cooking, biomass burning, coal burning, dust and traffic, are 1~2, 5~7, 3~26, 3~10, and 6~9 %, respectively. The second organic and inorganic-rich show relatively high contributions to $PM_{2.5}$, which can reach up to 12~25 and 14~61 %, respectively.

Table 1 Health effect of different MNPs

Type of MNP	Health effect	References
Cu, Cd, Pb	Toxicity to microorganism and soil microbe activity, cytotoxicity, membrane damage, inflammatory response, and oxidative stress	Guo et al. (2011)
Au, Ni	Affects cellular micromotility, mitochondrial damage, autophagy, oxidative stress, bioaccumulation in important body organs, acute inflammation and apoptosis in the liver, adverse effect on human sperm motility, penetration of gold nanoparticles into sperm head and tail	Brant and Lecoanet (2005); Tarantola et al. (2009); Pan et al. (2009); Wiwanitkit et al. (2009); Cho et al. (2009); Li et al. (2010); Lasagna-Reeves et al. (2010)
Ag	Cytotoxicity and chromosome instability, oxidative stress, apoptosis, intracellular calcium transients, cell cycle arrest, interference with DNA replication fidelity, mammalian cells, free radical-induced oxidative stress and alteration of gene expression, blood–brain barrier destruction and astrocyte swelling, neuronal degeneration, and induce brain edema formation	Hsin et al. (2008); Kawata et al. (2009); Asharani et al. (2009a, b); Foldbjerg et al. (2011)
ZnO, Al_2O_3, Fe_2O_3, Fe_3O_4	No significant cellular toxicity, unstable cytotoxic and even genotoxic for cellular organisms	Auffan et al. (2009); Miura and Shinohara (2009); Lopez-Moreno et al. (2010);
TiO_2, CeO_2, SiO_2	DNA damage, an inhibitory effect of superparamagnetic iron oxide nanoparticles on osteogenic differentiation, alteration of calcium homeostasis and gene expression in diverse mammalian systems, toxic to bacteria, the nematode, and aquatic species	Gaiser et al. (2009); Jiang et al. (2009); Kasemets et al. (2009); Zhu et al. (2009)

MNP manufactured nanoparticle

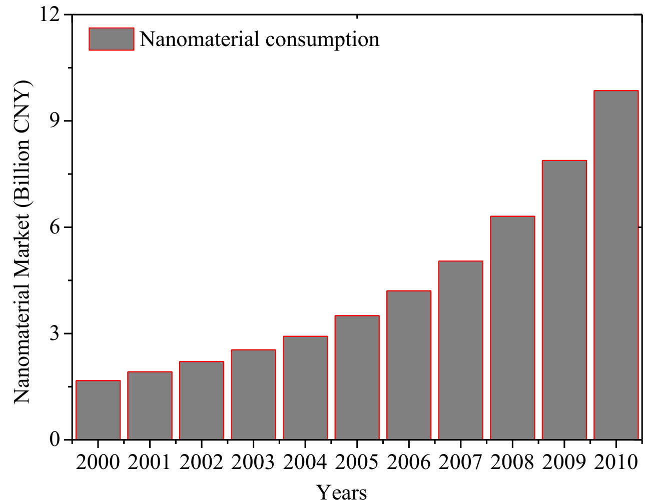

Fig. 2 Nanomaterial consumption in China from 2000 to 2010

An important source of $PM_{2.5}$ is from diesel exhaust, which is a complex mixture of hundreds of constituents in either gas or particle form (Wichmann 2007). The diesel exhaust typically mainly consist of carbon and absorbed organic compounds and other metals and trace elements, thus they are highly respirable and have a large surface area (Risslera et al. 2012). The diesel exhaust particles entering the respiratory tract would be a risk factor for the development of diseases of the respiratory system (Yoshizaki et al. 2015). Long-term exposure to diesel exhaust particles can cause acute irritation and neurophysiological, respiratory, and asthma-like symptoms (Wichmann 2007; Yoshizaki et al. 2015). In China, for diesel vehicles, China IV vehicles have been eligible for type approval since 2010, but China III vehicles may still be sold. Dong et al. (2014) have reported that the carbonyl emission of diesel vehicle would reach up to 45.8 Gg which is close to 58.4 Gg from gasoline-powered vehicles.

Although China is faced with serious $PM_{2.5}$ pollution, the local government still tends to keep the $PM_{2.5}$ monitor data confidential. This is because in a short time, the local government must sacrifice development in order to enhance the monitoring and management of $PM_{2.5}$. For example, during November 10, 2011 to December 21, 2011, Beijing experienced many instances of heavy fog weather and serious air pollution-related accidents wherein the air-pollution index (API) exceeded 500, and the $PM_{2.5}$ levels also exceeded the domain value of the highest pollutant category (People Net 2011). However, the Environmental Protection Agency (EPA) in Beijing published its monitoring data, claiming that the Beijing air quality API ranged from 150 to 170, and the primary pollutant was inhalable PM, which fell to the slight-pollutant category. The $PM_{2.5}$ monitoring data reported by the EPA Beijing were different from the observations reported by the United States Embassy in China. The U.S. Embassy

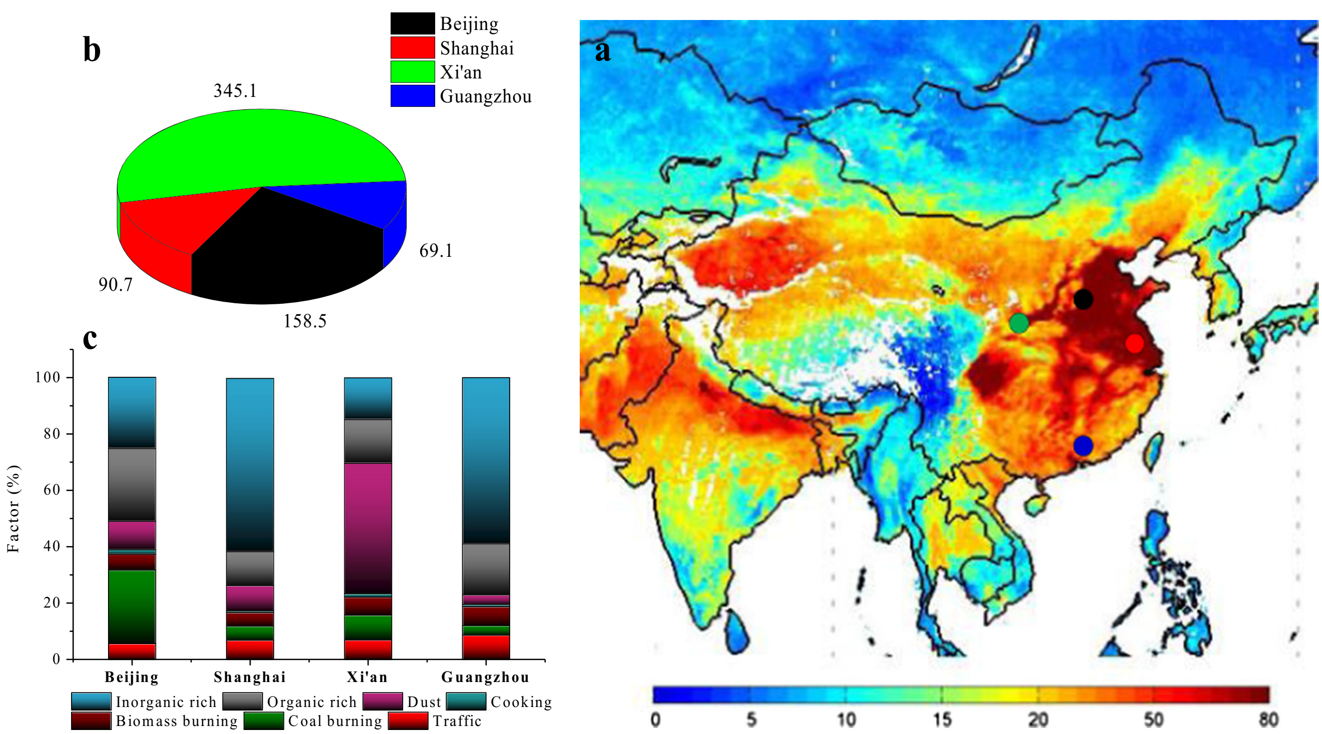

Fig. 3 $PM_{2.5}$ distribution in China (**a**); average $PM_{2.5}$ concentration level in four major cities in China (**b**); the source proportion of $PM_{2.5}$ in four major cities in China (**c**)

reported that the air-quality index was worse than the health index, and the $PM_{2.5}$ index was 511, defined as "crazy bad" level. In China, PM $_{2.5}$ has been found to be the primary pollutant in urban areas. However, the EPA Beijing refuses to release any of the $PM_{2.5}$ monitoring data, repeatedly using the excuse that the data is only accessible for scientific research.

Health effect of MNPs in China

MNP is a major risk placed on human health because it is associated with the presence of inflammatory markers and oxidative stress in the lungs, where the health effects depend on the concentration and emission sources (Duvall et al. 2008; Romieu et al. 2008). Many reports have showed that exposure to $PM_{2.5}$ leads to adverse health effects, particularly cardiovascular and respiratory diseases, as well as premature death (USEPA 2009). Moreover, fine particles of $PM_{2.5}$ are proved to be more strongly associated with increments in mortality than coarse particles when considering the mass concentration (Hernández-Mena et al. 2011) and the effects of $PM_{2.5}$ depending on their chemical constituents, including trace elements such as heavy metals, whose presence is attributable to the toxicity of the particles. However, there are few epidemiological studies on the health effects of short-term or long-term exposure to MNPs pollution in the Chinese population, especially on mortality and morbidity.

Figure 4 demonstrates the main diseases of inpatients related to nanoparticle pollution in city and county-level hospitals between 2010 and 2011. As Fig. 4 shows, in China, the first three kinds of diseases related to MNPs of inpatients in hospital between 2010 and 2011 are the disease of respiratory system, the disease of injury, poisoning, and external causes, and the disease of the digestive system, respectively. The total contribution of these three types of diseases takes a large proportion of the whole inpatients in a hospital. According to statistical data from the Ministry of Health, the main diseases of

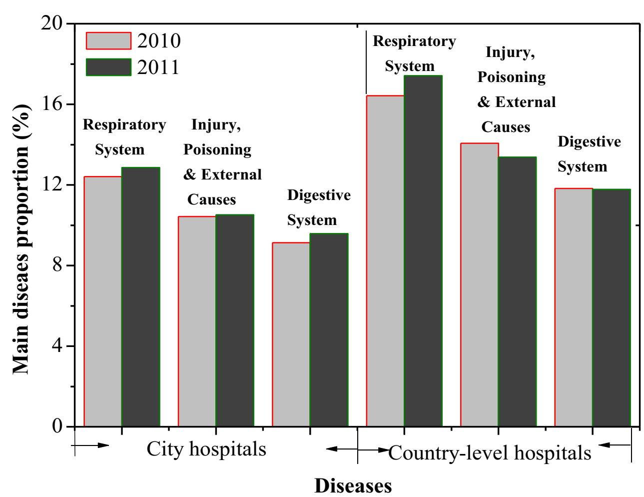

Fig. 4 Main diseases of inpatients in city and county-level hospitals between 2010 and 2011

inpatients in a hospital were higher in country-level hospitals than in city hospitals (CSIMH 2011). Recently, the government has been pushing the relocation of polluting industrial facilities to smaller cities in order to improve the mega cities' air quality. It can be expected that the incident of main disease in counties or in smaller cities will gradually exceed that in mega cities in China. The other reason is that the medical resources and living conditions in big cities are far beyond than that in counties or smaller cities. In addition, due to the unequal education resources in mega cities and smaller cities, people in mega cities are more aware of their health and environmental protection than the individuals in rural areas. Therefore, the current inpatient data is biased because of the easy accessibilities of medical resources in mega cities, as well as the awareness of health conditions among people in mega cities.

In China, many epidemiological studies have been conducted about the correlation between both mortality and morbidity and the increased $PM_{2.5}$ levels (Ma et al. 2011). Figure 5 demonstrates the significantly correlated relationship between short-term exposure to $PM_{2.5}$ and excessive risk for morbidity, including hospital admissions and prevention, and mortality from cardiovascular and respiratory diseases in three major cities in China. As it is shown in Fig. 5, in China, respiratory diseases have a generally stronger correlation with total mortality than other diseases, and cardiorespiratory mortality ranks as the second correlated casualty with respiratory diseases. However, in Beijing and Shenyang, the mortality risks of respiratory diseases are equal to that of cardiovascular, which is different from what has been reported in USEPA (2009). According to the USEPA (2009), the outdoor air pollution is the biggest environmental challenge for public health in China. Short-term epidemiological studies in China have shown that $PM_{2.5}$ affects the respiratory and cardiopulmonary systems, increases the health-care utilization levels, and increases the cardiopulmonary mortality rate. Increased mortality due to pulmonary and cardiovascular diseases has been reported in the studies focusing on long-term scale observation. In a benchmark experimental study, 552,000 subjects and 16 years of follow-up experiments are conducted (American Cancer Society Study). The experiments found out that each additional 10 mg of $PM_{2.5}$ will lead to an increase of cardiovascular mortality by 8~18 % (Pope et al. 2004).

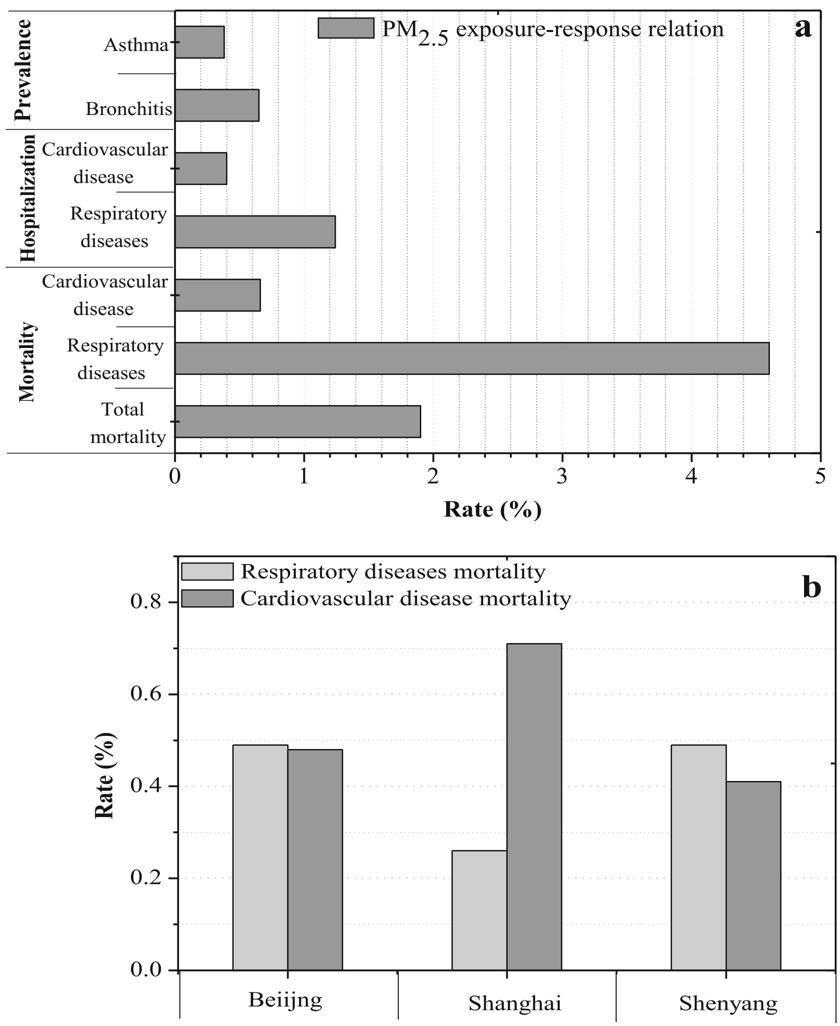

Fig. 5 Change of prevalence, hospitalization rate, and mortality with an increase of 10 μg/m^3 concentration of $PM_{2.5}$ in China (**a**); change of respiratory and cardiovascular disease mortalities in major cities of China, such as Beijing, Shanghai, and Shenyang, with an increase of 10 μg/m^3 concentration of $PM_{2.5}$ (**b**)

How to cope with increasing nanoparticle pollution in the future

As rapid economic development continues in China, it is urgent to regulate the occupational identification legislation in China with the intention of controlling and reducing risk of exposure of nanopollution on human beings. Currently, the use of nanomaterials is expanding in many processes of manufacturing, such as cosmetics, energy sources, coating processes, pharmaceuticals, and other industrial sectors. At the same time, people are becoming more and more aware of the nanopollution which may arise from the introduction of nanomaterials into everyday life. Another public concern focuses on the potential impacts or risk management of the nanomaterials on the environment and human health.

In China, according to the law made by the Ministry of Health, only the Center for Disease Control and Prevention, which belongs to the health bureau, has the official authority to quantify MNP amounts and judge if an injury is or is not caused by MNP. In China, ordinary workers who need to make occupational identification are mostly from local big enterprises which have government-related projects or make great contributions to local GDP. Once the workers from these enterprises or companies apply for their occupational identification via the local Center for Disease Control and Prevention, the identification result or application process could be manipulated by the local government. Therefore, it is very difficult for normal citizens in China to apply for official occupational identification. If the local Center for Disease Control and Prevention show that the diagnose results show disadvantages to those enterprises or companies, the enterprise or company could be punished or closed. This result is unflavored by the local government because great GDP losses will happen if these big enterprises holding government projects and companies contributing to local economics are shut down. The other reason is that the number of Centers for Disease Control & Prevention with the service of providing identification qualification report is very less. Most of the centers with occupational identification quantification are distributed in big or moderate cities. The number of Centers for Disease Control and Prevention from 2005–2011 was not increased. In contrast, the number of Centers for Disease Control and Prevention was reduced from 3585 to 3484, which decreased by 2.7 % (CSIMH 2011). The fewer locations of qualified Center for Disease Control and Prevention increase the difficulty for ordinary workers to apply their official occupational identification. Therefore, it is necessary to establish more occupational disease diagnosis centers and give more identification qualification to hospital and local clinics; thus, more ordinary workers who suffer long-term MNP pollution will be able to easily apply for their occupational identification. One point we would like to make is that in China, the potentials and processes of occupational identification for ordinary workers are essentially linked with the likelihood of MNP-induced health issues and casualties. The legislation of MNP-related matters should also take the occupational identification process for ordinary workers into consideration. The people could be frequently exposed to MNPs including ordinary workers in MNP-related manufacturing industries and consumers of products made from MNP materials.

Perspective and conclusion

In China, the general public still lacks the knowledge and awareness of nanopollution. To educate the general public of the consequences of nanopollution, the first vital step is to define nanotechnology and nanomaterials. A precise and accurate definition deliverable to public will help the government to design proper regulations and laws to determine which nanomaterials and applications will be exempted from pollution control and which MNP-related producers must comply with the manufacturing standards. In order to ensure the protection of health and the environment, a safety and necessity evaluation should be required prior to commercialization of any nanomaterial-made products. The burden of meeting the safety requirements should be placed on the industry itself to ensure that user-relevant data can be generated and monitored by the public. It is also important to enforce manufacturers to take the responsibilities for their nanomaterial and/or product throughout the life cycles so that the risks of potential exposure of MNP to the human body can be minimized. The suggestions made for redesigning the regulations on MNP-related industry could be reached by the government's monetary incentive program or green-technology innovation reward program.

The changes of nanopollution in China are dramatic but still remain difficult to be accurately estimated. Energy consumption in China, which extensively contributes to nanoparticle pollution, has been increasing along with the rapid economic development in China over the recent decade. The energy consumption growth has aggravated the $PM_{2.5}$ pollution, although the Chinese government has made great efforts to reduce the total amount of $PM_{2.5}$ pollution and implemented the strictest pollution control measures in the history. The details of the measures are not presented in this paper, but the consequences of these strictest measures have been proved to be effective for many pollution-generating industries and sources, such as vehicle emissions industry, construction, and so forth. Meanwhile, the dilemma between reducing air pollution and promoting city economic development in China will still remain a problem (Gao and Xia 2011).

The lack of sufficient data on MNP risk assessment still makes it difficult for the government and communities to evaluate the different positive or negative aspects of nanotechnology. To assess and ultimately reduce the apparent risk to the environment and to human health, the potential of exposure to these emerging nanomaterials must be taken into account. Similar to legacy and other classes of emerging MNPs, a general procedure for quantifying MNPs in environmental samples include extraction, characterization, and instrumental quantification techniques. Existing methods to quantify MNPs include the refinement of relationships based on MNP behavior, the establishment of a quantitative basis measuring MNP transport and persistence, the application of relevant toxicological and regulatory limits on MNP concentrations in consumer products, and the establishment of a monitoring system for MNPs in the environment.

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References

Asharani PV, Hande MP, Valiyaveettil S (2009a) Antiproliferative activity of silver nanoparticles. BMC Cell Biol 10:65

AshaRani PV, Low Kah Mun G, Hande MP, Valiyaveettil S (2009b) Cytotoxicity and genotoxicity of silver nanoparticles in human cells. ACS Nano 3(2):279–290

Auffan M, Rose J, Wiesner MR, Bottero JY (2009) Chemical stability of metallic nanoparticles: a parameter controlling their potential cellular toxicity in vitro. Environ Pollut 157:1127–1133

Baun A, Sørensen SN, Rasmussen RF, Hartmann NB, Koch CB (2008) Toxicity and bioaccumulation of xenobiotic organic compounds in the presence of aqueous suspensions of aggregates of nano-C_{60}. Aquat Toxicol 86:379–387

Bihari P, Vippola M, Schultes S, Praetner M, Khandoga AG, Reichel CA, Coester C, Tuomi T, Rehberg M, Krombach F (2008) Optimized dispersion of nanoparticles for biological in vitro and in vivo studies. Part Fibre Toxicol 5:14

Brant J, Lecoanet H (2005) Wiemer M R (2005) Aggregation and deposition characteristics of fullerene nanoparticles in aqueous systems. J Nanopart Res 7(4/5):545–553

Buffle J (2006) The key role of environmental colloids/nanoparticles for the sustainability of life. Environ Chem 3(3):155–158

Centre for Statistic Information Ministry of Health (CSIMH), Health development statistical bulletin in China, 2011.

China National Environmental Monitoring Centre (CNEMC). Air quality rport in 74 Chinese cities in March and the first quarter 2013. (in Chinese).

Cho WS, Cho M, Jeong J, Choi M, Cho HY, Han BS, Kim SH, Kim HO, Lim YT, Chung BH (2009) Acute toxicity and pharmacokinetics of 13 nm-sized PEG-coated gold nanoparticles. Toxicol Appl Pharmacol 236(1):16–24

Cunningham MJ. Gene-cellular interactions of nanomaterials: genotoxicity to genomics. In: Monteiro-Riviere NA, Tran CL(Eds.), Nanotoxicology Characterization, Dosing and Health Effects. Informa healthcare, New York, USA, 2007.

Dhawan A, Sharma V (2010) Toxicity assessment of nanomaterials: methods and challenges. Anal Bioanal Chem 398:589–605

Dong D, Shao M, Li Y, Lu S, Wang Y, Ji Z, Tang D (2014) Carbonyl emissions from heavy-duty diesel vehicle exhaust in China and the contribution to ozone formation potential. J Environ Sci 26(1):122–128

Duvall MR, Norris AG, Dailey AL, Burke MJ, McGee KJ, Gilmour IM, Gordon T, Devlin BR (2008) Source apportionment of particulate matter in the U.S. and associations with lung inflammatory markers. Inhal Toxicol 20:671–683

Foldbjerg R, Dang DA, Autrup H (2011) Cytotoxicity and genotoxicity of silver nanoparticles in the human lung cancer cell line, A549. Arch Toxicol 85(7):743–750

Gaiser BK, Fernandes TF, Jepson M, Lead JR, Tyler CR, Stone V (2009) Assessing exposure, uptake and toxicity of silver and cerium dioxide nanoparticles from contaminated environments. Environ Heal 8(Suppl 1):S2

Gao Y, Xia J (2011) Chromium contamination accident in China: viewing environment policy of China. Environ Sci Technol 45(20):8605–8606

Gao Y, Luo ZX, He NP, Wang MK (2013) Metallic nanoparticle production and consumption in China between 2000 and 2010 and associative aquatic environmental risk assessment. J Nanoparticle Res 15:1681

Gottschalk F, Nowack B (2011) The release of engineered nanomaterials to the environment. J Environ Monit 13:1145–1155

Groso A, Petri-Fink A, Magrez A, Michael R, Meyer T (2010) Management of nanomaterials safety in research environment. Part Fibre Toxicol 7:40

Guo GY, Yuan T, Wang WH, Li D, Cheng JP, Gao Y, Zhou P (2011) Bioavailability, mobility, and toxicity of Cu in soils around the dexing Cu mine in china. Environ Geochem Health 33:217–224

Hernández-Mena L, Murillo-Tovar M, Ramírez-Muńíz M, Colunga-Urbina E, Garza-Rodríguez I, Saldarriaga-Noreňa H (2011) Bull Environ Contam Toxicol 87: 545–549

Hsin YH, Chen CF, Huang S, Shih TS, Lai PS, Chueh PJ (2008) The apoptotic effect of nanosilver is mediated by a ROS- and JNK-dependent mechanism involving the mitochondrial pathway in NIH3T3 cells. Toxicol Lett 179(3):130–139

Huang RJ, Zhang YL, Bozzetti C, Ho KF, Cao JJ, Han YM, Daellenbach KR, Slowik JG, Platt SM, Canonaco F, Zotter P, Wolf R, Pieber SM, Bruns EA, Crippa M, Ciarelli G, Piazzalunga A, Schwikowski M, Abbaszade G, Schnelle-Kreis J, Zimmermann R, An ZS, Szidat S, Baltensperger U, Haddad I, Prévôt A (2014) High secondary aerosol contribution to particulate pollution during haze events in China. Nature 514:218–222

Jiang W, Mashayekhi H, Xing B (2009) Bacterial toxicity comparison between nano- and micro-scaled oxide particles. Environ Pollut 157(5):1619–1625

Kasemets K, Ivask A, Dubourguier HC, Kahru A (2009) Toxicity of nanoparticles of ZnO, CuO and TiO_2 to yeast Saccharomyces cerevisiae. Toxicol In Vitro 23(6):1116–1122

Kawata K, Osawa M, Okabe S (2009) In vitro toxicity of silver nanoparticles at noncytotoxic doses to HepG2 human hepatoma cells. Environ Sci Technol 43(15):6046–6051

Kim CS, Jaques PA (2000) Respiratory dose of inhaled ultrafine particles in healthy adults. Philos Trans R Soc Lond A 358:2693–2705

Lasagna-Reeves C, Gonzalez-Romero D, Barria MA, Olmedo I, Clos A, Sadagopa Ramanujam VM, Urayama A, Vergara L, Kogan MJ, Soto C (2010) Bioaccumulation and toxicity of gold nanoparticles after repeated administration in mice. Biochem Biophys Res Commun 393(4):649–655

Li JJ, Hartono D, Ong CN, Bay BH, Yung LY (2010) Autophagy and oxidative stress associated with gold nanoparticles. Biomater 31(23):5996–6003

Linkov I, Satterstrom FK, Monica JC Jr, Hansen SF, Davis TA (2009) Nano risk governance: current developments and future perspectives. Nanotechnol Law Bus 6:203–220

Lopez-Moreno ML, De-la-Rosa G, Hernandez-Viezcas JA, Castillo-Michel H, Botez CE, Peralta-Videa JR, Gardea-Torresdey JL (2010) Evidence of the differential biotransformation and genotoxicity of ZnO and CeO_2 nanoparticles on soybean (glycine max) plants. Environ Sci Technol 44:7315–7320

Lynch I, Dawson KA (2008) Protein–nanoparticle interactions. Nano Today 3(1–2):40–47

Ma YJ, Chen RJ, Pan GW, Xu XH, Song WM, Chen BH, Kan HD (2011) Fine particulate air pollution and daily mortality in Shenyang, China. Sci Total Environ 409:2473–2477

Mayer A, Vadon M, Rinner B, Novak A, Wintersteiger R, Fröhlich E (2009) The role of nanoparticle size in hemocompatibility. Toxicology 258:139–147

McNeil SE (2005) Nanotechnology for the biologist. J Leukoc Biol 78: 585–594

Miao CY, Ni JR, Borthwick AGL (2010) Recent changes in water discharge and sediment load of the Yellow River basin, China. Prog Phys Geog 34(4):541–561

Miao CY, Ni JR, Borthwick AGL, Yang L (2011) A preliminary estimate of human and natural contributions to the changes in water discharge and sediment load in the Yellow River. Global Planet Change 76(3–4):196–205

Miao CY, Ashouri H, Hsu K, Sorooshian S, Duan QY (2015) Evaluation of the PERSIANN-CDR daily rainfall estimates in capturing the behavior of extreme precipitation events over China. J Hydrometeorol 16:1387–1396

Ministry of Industry and Information Technology of the People's Republic of China (MIIT) (2011) Chinese nano-materials industry market and investment forecast report in 2011–2017.

Miura N, Shinohara Y (2009) Cytotoxic effect and apoptosis induction by silver nanoparticles in HeLa cells. Biochem Biophys Res Commun 390(3):733–737

Nowack B, Bucheli TD (2007) Occurrence, behavior and effects of nanoparticles in the environment. Environ Pollut 150(1):5–22

O'Brien NJ, Cummins EJ (2011) A risk assessment framework for assessing metallic nanomaterials of environmental concern: aquatic exposure and behavior. Risk Anal 31(5):706–726

Pan Y, Leifert A, Ruau D, Neuss S, Bornemann J, Schmid G, Brandau W, Simon U, Jahnen-Dechent W (2009) Gold nanoparticles of diameter 1.4 nm trigger necrosis by oxidative stress and mitochondrial damage. Small 5(18):2067–2076

People Net. http://politics.people.com.cn/GB/70731/16494511.html. 2011.

Poland CA, Duffin R, Kinloch I, Maynard A, Wallace WA, Seaton A, Stone V, Brown S, Macnee W, Donaldson K (2008) Carbon nanotubes introduced into the abdominal cavity of mice show asbestos like pathogenicity in a pilot study. Nat Nanotechnol 3:423–428

Pope CA, Burnett RT, Thurston GD, Thun MJ, Calle EE, Krewski D, Godleski JJ (2004) Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation 109:71–77

Pui DYH, Chen SC, Zuo ZL (2014) $PM_{2.5}$ in China: measurements, sources, visibility and health effects, and mitigation. Particuology 13:1–26

Risslera J, Swietlicki E, Bengtsson A, Boman C, Jo P, Sandströmd T, Blomberg A, Löndahl J (2012) Experimental determination of deposition of diesel exhaust particles in the human respiratory tract. J Aerosol Sci 48:18–33

Romieu I, Barraza A, Escamilla C, Almstrand C, Díaz D, Sly P, Carin A (2008) Exhaled breath malondialdehyde as a marker of effect of exposure to air in children with asthma. J Allergy Clin Immunol 121:903–909

Savolainen K, Alenius H, Norppa H, Pylkkänen L, Tuomi T, Kasper G (2010a) Risk assessment of engineered nanomaterials and nanotechnologies—a review. Toxicology 269(2–3):92–104

Savolainen K, Pylkkäen L, Norppa H, Falcka G, Lindberg H, Tuomi T, Vippola M, Alenius H, Hämeri K, Koivisto J, Brouwer D, Mark D, Bard D, Berges M, Jankowsk E, Posniak M, Farmer P, Singh R, Krombach F, Biharig P, Kasper G, Seipenbusch M (2010b) Nanotechnologies, engineered nanomaterials and occupational health and safety—a review. Saf Sci 48:957–963

Sina, http://news.sina.com.cn/s/2009-09-16/220418665133.shtml. 2009. (In Chinese)

Song Y, Li X, Du X (2009) Exposure to nanoparticles is related to pleural effusion, pulmonary fibrosis and granuloma. Eur Respir J 34:559–567

Sweet L, Strohm B (2006) Nanotechnology-life-cycle risk management. Hum Ecol Risk Assessment Intern J 12(3):528–551

Tarantola M, Schneider D, Sunnick E, Adam H, Pierrat S, Rosman C, Breus V, Sonnichsen C, Basche T, Wegener J, Janshoff A (2009) Cytotoxicity of metal and semiconductor nanoparticles indicated by cellular micromotility. ACS Nano 3(1):213–222

The World Market for Nanotechnology and Nanomaterials in Consumer Products (NNCP), 2010.

Theng BKG, Yuan G (2008) Nanoparticles in the soil environment. Elements 4(6):395–399

Thomas K, Aguar P, Kawasaki H, Morris M, Nakanishi J, Savage N (2006) Strategies for safety evaluation of nanomaterials, part VIII: international efforts to develop risk-based safety evaluations for nanomaterials. Toxicol Sci 92:23–32

Thomas T, Bahadori T, Savage N, Thomas K (2009) Moving toward exposure and risk evaluation of nanomaterials: challenges and future directions. Nanomed Nanobiotechnol 1:426–433

Tsuji JS, Maynard AD, Howard PC, James JT, Lam CW, Warheit DB, Santamaria AB (2006) Research strategies for safety evaluation of nanomaterials, part IV: risk assessment of nanoparticles. Toxicol Sci 89:42–50

USEPA. (2009). Integrated science assessment for particulate matter (final report)

Wichmann HE (2007) Diesel exhaust particles. Inhal Toxicol 19(Suppl 1):241–244

Wiwanitkit V, Sereemaspun A, Rojanathanes R (2009) Effect of gold nanoparticles on spermatozoa: the first world report. Fertil Steril 91(1):7–8

Yoshizaki K, Brito JM, Moriya HT, Toledo AC, Ferzilan S, Ligeiro de Oliveira AP, Machado ID, Farsky SH, Silva LF, Martins MA, Saldiva PH, Mauad T, Macchione M (2015) Chronic exposure of diesel exhaust particles induces alveolar enlargement in mice. Respir Res 16:18

Zhu X, Wang J, Zhang X, Chang Y, Chen Y (2009) The impact of ZnO nanoparticle aggregates on the embryonic development of zebrafish (*Danio rerio*). Nanotechnol 20(19):195103