Published in final edited form as:

Int J Occup Environ Health. 2010 ; 16(4): 378–387.

Nanotechnology and Exposure Science:

What Is Needed To Fill the Research and Data Gaps for Consumer Products

PAUL J. LIOY, YEVGEN NAZARENKO, TAE WON HAN, MARY JEAN LIOY, and GEDIMINAS MAINELIS

Environmental and Occupational Health Sciences Institute, Piscataway, NJ, US (PJL, GM); Robert Wood Johnson Medical School (RWJMS)-University of Medicine and Dentistry of New Jersey (UMDNJ), and Rutgers University, Piscataway, NJ, USA (PJL); Rutgers University, Department of Environmental Sciences, New Brunswick, NJ, USA (TWH, YN, GM); NU Horizon E&H LLC, Cranford, NJ, USA (MJL)

Abstract

This article discusses the gaps in our understanding of human exposures to nanoparticles stemming from the use of nanotechnology-based consumer products by the general public. It also describes a series of steps that could be taken to characterize such exposures. The suggested steps include classification of the nanotechnology-based products, simulation of realistic exposure patterns, characterization of emissions, analysis of the duration of activities resulting in exposures, and consideration of the bioaccessibility of nanoparticles. In addition, we present a preliminary study with nanotechnology-based cosmetic powders where particle release was studied under realistic powder application conditions. The data demonstrated that when nanotechnology-based cosmetic powders were used, there was a potential for inhaling airborne particles ranging in size from tens of nanometers to tens of micrometers.

Keywords

exposure science; nanoparticles; nanotechnology; consumer products; particle emission

INTRODUCTION

To date, the serious issue of exposures to engineered nanoparticles to the general public has not been the subject of systematic research projects.¹ This, however, is in contrast to the studies that are being done on the basic toxicology of selected engineered nanoparticles used as raw or bulk materials and the recent work on exposure to workers during the production of engineered nanoparticles.^{2,3} Research has also been conducted on the fate of nanoparticles in the ecosystem.⁴ The former and the latter are important; however, they leave out the ways in which the general public is exposed and the intensity of those exposures^{5,6} to the general public in regards to consumer products with nanoparticles embedded in them (such as fabrics) or with nanoparticles that are an integral part of the

Send correspondence to: Gediminas Mainelis, Rutgers University, Department of Environmental Sciences, 14 College Farm Rd., New Brunswick, NJ 08901, USA; <mainelis@envsci.rutgers.edu>..

Disclosures: The authors declare no competing interests.

product during its use (such as facial cosmetic applications or spray products). Although a recent study investigating particle release from a commercially available water-based nanosilver spray product,⁷ is one of the few studies looking at nanoparticle release, in most risk characterizations and assessments, exposure assessments, especially under realistic conditions, is missing. Further, data gaps on potential exposures to engineered nanoparticles present in consumer products are even larger. In the case of fabric, cosmetics, and/or sprays, the lack of exposure research in the literature is apparent: only limited data are available on the emissions of nanoparticles and human contacts that occur during normal use and after wear and tear has degraded the product during its repeated applications or uses.^{8,9} These types of experiments must be conducted and then coupled with relevant studies of the products themselves (that is, of the nanoparticles and structures within the products) as well as with animal models for exposure patterns and intensities that could be encountered during product use.

The discussion below describes a series of steps that could be taken to characterize human exposures to nanoparticles stemming from the use of nanotechnology-based consumer products. In addition, we present a preliminary study with nanotechnology-based cosmetic powders where particle release was studied under realistic powder application conditions and placed within the five-step process that we outline for understanding nanomaterial exposures.

BACKGROUND AND GENERAL DISCUSSION

In the US, the National Nanotechnology Initiative (NNI) defines nanotechnology as “the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications.”¹⁰ By comparison, the European Commission describes nanotechnology as the study of phenomena and fine-tuning of materials at atomic, molecular, and macromolecular scales, where properties differ significantly from those at a larger scale.¹¹

Due to the unique physical, chemical, and biological properties of these engineered materials at such a small scale, nanomaterials are increasingly being used to improve properties of various consumer products, including sunscreens, paints, tires, drugs, shampoos, cleaning sprays, cosmetics, and clothing. The Project on Emerging Nanotechnologies (PEN), a joint venture by Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts, has developed an inventory cataloging more than 1000 nanotechnology-based consumer products currently on the market in a variety of categories as of June 2010,¹² and while individual entries into the inventory change and are sometimes removed, their total number in the database continues to increase. As the use of such products increases, the potential for consumer exposure to nanoparticles increases as well, and there is an urgent need to address exposure and risk assessment data gaps.¹

After reviewing some of the products in the above-mentioned database, it becomes evident that nanomaterials are present in many products designed to be in close contact with the human body. In a review published in 2006, Davies¹³ indicated that “many of the current commercial applications of nanotechnology were high-exposure uses such as cosmetics,

clothing and drugs.” Davies also indicated that, “The only way to deal with potential adverse effects of nanotechnology (NT) in most cases will be to design the product or tailor the use of the material so that the NT material does not get into the environment or the human body in the first place.” Also, as noted by Thomas et al. (2006), “[T]he population currently exposed to nanoscale materials in consumer products would be representative of the entire population” because many of these products appeal to a diverse range of individuals.¹⁴ In addition, it is expected that the consumer base will increase, thus increasing the potential for exposures and associated risks. Therefore, the issue becomes how to achieve *de minimis* exposure to nanoparticles associated with unidentified hazards in order to achieve *de minimis* risk to the consumers.

The potential for negative health effects due to exposure to individually dispersed nanoparticles could be inferred from studies examining the toxicity of naturally occurring or anthropogenic airborne particles (such as those from fires or motor vehicle emissions) that are less than 100 nm in diameter (often designated as ultrafine particles). Studies on ultrafine particles have found a link in test populations between morbidity and mortality and the intensity of exposure to such particles.^{15,16} Nanometer-sized particles have been found to play a special role in aerosol dosimetry¹⁷ and their contribution to an observed increase in morbidity and mortality has been suggested.¹⁸ Sudden death has been found to be associated with the particle number concentration (a proxy for ultrafine particles) in air pollution, particularly with the levels on the day of a patient’s death.¹⁹ Elevated daily ultrafine particle concentrations have been correlated with a decrease in peak expiratory flow and an increase in medication use in patients with chronic pulmonary diseases.²⁰ However, it is also known that ultrafine particles resulting from combustion quickly grow as they move away from the source of combustion, coagulating and becoming accumulation mode particles.²¹

Given such health concerns, the NNI has indicated that understanding the health and safety impacts of nanotechnology for researchers, workers, consumers, and the public is their top priority: “[T]he determination of population or population subgroup exposure is a very important aspect of assessing the potential environmental health burden of nanoparticle use, and at the present time it is an under-investigated issue.”¹⁰ According to NNI’s research strategy document, human and environmental exposure assessment would be carried out by the National Institute for Occupational Safety and Health (NIOSH), which focuses only on occupational hazards.²² Internationally, the Organisation for Economic Co-operation and Development has established a Working Party on Manufactured Nanomaterials (WPMN),²³ which have a dedicated Steering Group on Exposure Measurement to prioritize and mitigate exposures in occupational environments involving nanotechnology, but has no actual plans for consumer exposure research.

However, the environmental and human exposures that can lead to potentially adverse human health outcomes during the manufacturing, use, and final disposition of products containing engineered nanoparticles have not yet been adequately investigated.²⁴⁻²⁶ Existing studies already indicate that biocidal silver incorporated into textiles and plastics account for up to 15% of total silver released into water in the European Union.⁴ Some studies on occupational exposures have been performed and found that nanoparticles can be released during their production,^{2,27,28} but no widely accepted systematic approach has been

considered or is available for evaluating potential consumer risks associated with the use of nanotechnology-based products.¹ This point will be returned to in a later part of the discussion.

Numerous studies examining toxicity of nanomaterials have already been performed and summarized.²⁶ However, most of the studies primarily focus on *in vitro* techniques with few investigating actual inhalation and other exposure impacts and fate of nanomaterials as they are inhaled from the air into an active respiratory system or come in contact with the body via dermal or ingestion exposure routes. More importantly, data on acute toxicity and dose-dependent mortality are usually obtained with pure nanomaterials of certain characteristics and for specific exposure routes. Such data cannot be used directly to draw conclusions about health effects of exposures to nanoparticles from consumer products for several reasons, as discussed below.

1. As suggested in literature, the toxicological effects of nanomaterials are likely to change as the exposure route changes.²⁹ Due to the variety of available products and associated potential exposures, such as inhalation, absorption, and/or ingestion, exposure routes will vary depending on the product and its use. For products such as sprays, the airborne route is most likely due to the specific application mode of the products. The typical application of cosmetics results in dermal route exposure, but the process of applying cosmetic powders to the skin also results in the release of airborne particles, including those in the nanosize range. For clothing products, the primary contact area is skin, but the release of materials from the holding matrix would result in exposures to airborne particles as well. Nanomaterials can also be ingested with food and drugs. Not only is assessment of exposure to nanoparticles via various exposure routes necessary,^{1,30} but the assessment should also analyze bioavailability for each route of exposure.
2. Nanoparticles change en route from product matrix to actual consumer exposure. The size of nanomaterials incorporated into the consumer product may not be representative of the size of the particles released from the product during its application and use. This is due to the concepts of coagulation or agglomeration with other particles, including other nanoparticles. Due to the high surface area to volume ratio and high particle number concentrations, nanoparticles are likely to agglomerate³¹ and coagulate within the product or during particle release, and the larger size of resulting particles will have different patterns of deposition and impacts depending on whether the particles are inhaled or ingested or taken in via some other route. In that case, the mass of agglomerates deposited along a route of exposure might become the particle characteristic of concern. The importance of nanoparticle agglomeration in toxicity investigations has been stressed in several studies.^{32,33} For some nanomaterials, however, capping agents are used to prevent agglomeration, and thus potential problems will vary depending on the product type and manufacturer. The nature of these coagulated materials and the nature of holding forces also need investigation to determine whether or not the nanomaterials can be partially deagglomerated into smaller aggregates after entering the body. Such deagglomeration could facilitate particle entrance into

deeper points in the respiratory or circulatory system at some point after ingestion or inhalation.

3. Consumers are exposed to a mixture of nanoparticles and the product matrix holding the particles. In most of the studies on health effects of nanoparticles, exposures and toxicity are determined only to the specific nanoparticles that are produced in bulk for use in consumer products and not to the entire product matrix in which such particles are incorporated for a specific commercial product. During the actual use of a specific product, exposures would occur not only to the nanomaterials or their agglomerates, but also to other particles from the product, including those from the product matrix. An example would be a contact with the spray that contains nanoparticles and other materials. While there is a potential for occupational exposure during the manufacturing of the nanoparticles to be incorporated in sprays, the consumers who use the final product (the sprays themselves) may be exposed to aerosolized nanoparticles and their agglomerates as well as to other particles from the product, such as particles from carrier liquids.³⁴ Furthermore, various other materials that are included as an integral part of a consumer or industrial product might have particle size and surface area characteristics that mimic the nanotechnology product itself or obscure its presence, as in the case of nanotechnology-based fabrics. Although particles in the nanometer range are incorporated in such fabrics, the size of particles released from them due to abrasion and other mechanical disruption will be much larger, likely that of coarse particles.
4. Exposure to nanoparticles changes over prolonged use time. Exposures and associated health risks are likely to depend on the age of the product and its “wear and tear” (ability of the product matrix to hold the nanoparticles), as well as the duration of its use. For example, for clothing products, particle release could intensify as the holding matrix (that is, the fabric) weakens after prolonged use and multiple washing and dry cleaning cycles. However, once the fabric weakens, more nanoparticles could be removed by washing, thus possibly resulting in a reduced exposure. The dynamic equilibrium between the two processes would have to be determined experimentally. For products that require repeated applications, such as cosmetic creams, sprays, and brush-applied cosmetics, the issue may be bioaccumulation in the body over a long period of frequent use at low concentrations as opposed to the impact of exposure to a bolus of material, such as that inhaled during a single use.

STUDY NEEDS

To investigate potential health risks and toxicological effects associated with the use of nanotechnology-based consumer products, one should first examine the release of nanoparticles and associated human exposures in a way that simulates the actual handling and use of nanomaterials and their products. Such studies would be able to determine and quantify human exposures to engineered nanoparticles at home and in the personal cloud (air pollutants surrounding a person, usually at concentrations higher than those detected by stationary monitors over the course of the day). Once information on exposures is obtained,

the results can be used in exposure and hazard characterizations for critical risk assessments. Nanotechnology risk assessment up to now has only provided studies on quantitative hazard assessment (such as information on overall toxicity),²⁶ but not on quantitative human exposure assessment, which is the second half of risk assessment. The results from both qualitative and quantitative assessments can also be used to design appropriate health studies to assess health risks due to nanotechnology-based products in general commerce and manufacturing.

As with other toxicants, data on human exposures are crucial for risk assessments for nanomaterials.³⁵ Without a quantitative and accurate assessment of potential realistic exposures to releases from consumer products, risk assessments will not have the same quality of data that can be used to define hazards in a risk characterization. Thus, it is necessary to characterize the nanomaterials incorporated in the consumer products, investigate their potential alterations during usage (such as agglomeration), and analyze exposure to engineered nanoparticles during the product use. In fact, exposure monitoring has been indicated as one of the five research challenges that would help support evidence-based decisions on using nanotechnology.³⁶

Thus, exposure studies have to be an integral part of risk assessments associated with the use of nanotechnology-based consumer products; this will require a series of carefully designed implementation steps. In the following discussion we would like to suggest several steps (Table 1) that could be used in exposure assessments and present some examples of data that could be obtained from those steps.

Step 1: Classification of the nanotechnology-based consumer products

Recent work by Hansen et al. (2008)³⁵ suggested dividing products into major product categories and then determining the chemical identity of the nanomaterials used in each category. Based their classification, most of the products in the PEN inventory, fall into “health and fitness” category, which, according to their analysis, also have the highest expected consumer exposure. The preliminary exposure data in this paper were determined for powders, which fall into the same category. The same authors also categorized products by the location of nanostructures and the likelihood of exposures, and also took into account the duration of contact. In addition to those product categories and their parameters we would like to suggest adding “exposure routes, in order of likelihood,” “population with likeliest exposure,” and “frequency and duration of each application/use.” We believe these groupings will aid in refining risk assessments and identifying populations most at risk, especially for products with repeated use, such as cosmetics. Table 2 presents an example of suggested categorization.

Step 2: The design of studies that simulate exposure for realistic patterns of use and types of consumer products

These studies could focus on one or more exposure routes. The key word here is “realistic.” Accurate product use information is essential in designing any experiments with clothing, cosmetics, sprays, and other products. Such studies will need to mimic the activities of those

who use the products intensively and frequently. In addition, unintended uses that could lead to high exposures should be considered.

A study by Hansen et al.³⁵ estimated exposures using calculations for four product categories, including a spray product where inhalation was expected to be the primary exposure route. Such calculations have great merit and provide a first approximation of exposures; however, by their nature, calculations employ a number of parameters that in our opinion can be accurately determined only by measurements since they will vary from product to product even within the same category. Moreover, some of the calculation parameters have to be derived from the content of nanomaterial(s) in a product, information about which is available for only a limited number of products. In the case of sprays, some of the parameters that should be determined experimentally include concentrations of the substance in the air and inhaled quantities. The latter depends not only on the amount of particles released from the product and inhalation rate, it is also a function of particle size. Thus, to determine the amount of material that is inhaled and deposited in the lungs, one needs to know the size distribution of particles released from the products and then the size distribution that is presented to the respiratory system. The size distribution will depend on the product type and the release mode (for example, spray droplets, powder, and/or fragments of clothing) and can only be determined in experiments realistically simulating product use.

Step 3: Characterizations of particle release during product use

These experiments should look at a variety of release characteristics during normal product use. For example, emissions when the product is first used and then the emissions after the product has been in use for some time or after multiple applications. Exposure characterizations could also be influenced by emissions after multiple applications during a short period of time. Thus, intended product use information or surveys of actual usage are essential before such experiments are conducted to obtain information that can be generalized to the public at large. Pilot studies on emission rates can be conducted before survey information is available. In fact, in some cases such pilot studies can provide information on whether or not detailed studies are necessary or can be ignored because of the lack of potential exposures. When analyzing particle release, their multiple characteristics should be investigated, including particle number, surface area, shape, or other physical and chemical properties.³⁰

Step 4: Analysis of the duration and intensity of activities during which the nanoparticles or agglomerates from the products are released

These are necessary types of emission studies that can determine the presence or absence of potential exposures. In some circumstances, there will be frequent applications of short duration and short exposures, as in the application of facial cosmetics. Other contacts will be less frequent and related to the “pigpen effect.” In Charles Shultz’s comic strip *Peanuts*, the character Pig Pen always has a cloud of dust around his body. In the 1970s, Lance Wallace coined the phrase “personal cloud” to suggest that there is a cloud of particles and gases that can be quantified around a person.³⁷ If properly examined this effect can describe many types of processes and distributions that can lead to contacts with particles and gases. In the

case of nanoparticles or their agglomerates, one would be attempting to measure the release of these materials around the head or the rest of the body. Then one could use this information to estimate potential doses to the body.

Step 5: Analysis of bioaccessibility of nanoparticles in both the lungs and digestive system

The studies could use simulated biofluids to examine the release of nanomaterials from the product matrix or from coagulated particles that are deposited intact as agglomerates in the lung or in the digestive system. These data can assist in designing studies that look at the transport of the releasable materials into the circulatory system and then individual organs.

EXPERIMENTAL ILLUSTRATION OF STUDY NEEDS

As an illustration of some of the steps among the study needs presented above we will describe a recent preliminary study to investigate potential inhalation exposure to particles released during the use of nanotechnology-based cosmetic powders.

Step 1: Classification of the nanotechnology-based consumer products

The cosmetic powders fall into “health and fitness” category, while some of their other parameters, such as likely exposure route, likely exposed population, anticipated frequency of use and duration, are provided in Table 2.

Step 2: The design of studies that simulate exposure for realistic patterns of use and types of consumer products

This study on nanotechnology-based cosmetic powders focused on an inhalation exposure route; the exposure scenario was realized by applying the powders in a realistic manner onto a female manikin’s face and then measuring the concentration and size distribution of particles that would be inhaled through the nose. Cosmetics, as mentioned above, are considered high exposure products.¹³ For the experiments, we selected three cosmetic powders that, according to the PEN inventory, are based on nanotechnology. We visited the manufacturers’ websites to verify that the presence of nanoparticles in those products was actually disclosed by the manufacturer. According to their designated application, the selected powders were a “blusher,” a “sunscreen powder,” and a “skin treatment powder.” According to its manufacturer, the “blusher” was based on a nanodispersion technology that creates an extremely fine and light powder. The ingredients of this product included talc, olefin polymers, aluminum-based compounds, silica, and others. The active ingredients in the “sunscreen powder” were titanium dioxide (25%) and zinc oxide (20%) in nanosize formulation. According to the manufacturer of the “skin treatment powder,” treatment ingredients included nanosize and included glycerin, silica, sodium salts, and various herbal extracts.

Step 3.Characterization of the particle release during the product use

The potential release and inhalation exposure to particles from the three selected cosmetic powders were determined when the products were applied to the female manikin’s face. Inhalation was simulated by sampling the released particles through stainless steel sampling

inlets installed in the manikin's nostrils. The air flow through the two stainless steel tubes was combined into one line via a metal Y-connector behind the manikin's nape and then split using a flow-splitter (TSI, Inc., Shoreview, MN) to measure the size and concentration of the "inhaled" particles using a scanning mobility particle sizer (SMPS 3936, TSI Inc.) and an aerodynamic particle sizer (APS 3320, TSI Inc.). The SMPS measured particles in 0.014–0.7 μm range, while the APS measured particles in 0.5–20 μm range. The devices operate at 0.3 and 5 l/min, respectively. The 5 l/min flow drawn by the APS was divided by the instrument into 1 l/min for sample analysis and 4 l/min for sheath flow rate. The SMPS measured the electrical mobility diameter and the APS measured aerodynamic mobility diameter. The definitions of the two diameters are identical for spherical particles of 1 g cm³ density. For the APS, powders were assumed to have density of 1 g cm³. All powders were applied using identical Kabuki brushes (Sephora USA, Inc., San Francisco, CA). All the connectors and sampling lines were of conductive material to minimize potential particle losses due to electrostatic effects. Since the SMPS provided a full scan of the entire size range of particles in three minutes, each test powder was continuously and uniformly (as much as possible) applied during that time period. The APS measured particle concentration every second and provided an average concentration for the three-minute interval.

The experiments were performed in a class II biosafety cabinet (NUAIRE Inc., Plymouth, MN), which was operated just before the exposure experiments to minimize the concentration of background particles, especially in the nanosized range. To minimize penetration of ambient particles into the biosafety cabinet, its opening was protected using plastic curtains. After each application the manikin's face was thoroughly cleaned with 70% ethanol and the air flow in the biosafety cabinet was activated to facilitate ethanol evaporation. Background measurements were also performed and the background particle concentration was subtracted from the powder data. The powder application order was randomized, each application was repeated three times, and the average number concentrations were calculated.

RESULTS

The data in Figure 1 presents concentrations of particles in the 0.014 to 0.7 μm range as measured by the SMPS. Figure 2 presents data for particles in the 0.5 to 20 μm range as measured by the APS. In both figures, the background particle concentration was subtracted. As can be seen from Figure 1, the particle concentration, expressed as $N/\log d \text{ cm}^3$, from three different powders stayed relatively close until approximately 50 nm, when the concentrations started to diverge. The concentration from skin treatment powder stayed relatively close to 1000 cm³, but the concentration from the sunscreen powder started to increase and reached a peak of close to 10⁵ cm³ at approximately 200 nm. The concentration of blusher seemed to steadily decrease and was below 10² cm³ for particles of 250 nm and larger. The presence of particles over the entire investigated size range was observed for all three powders. Based on these data, it is clear that nanosized particles were released during application of the nanotechnology-based powders and that there is a potential for inhaling these powders during their application.

As can be seen in Figure 2, when particles were measured in the 0.5 to 20 μm size range, the differences in simulated exposure size distributions obtained for different powders became more pronounced; but again for all test powders the presence of particles was observed over the entire measured size range. Among the three powders, the concentration of the blusher was the lowest over the entire size spectrum. The mode diameter was approximately 4 μm when concentration of 50 cm^3 (expressed as $N/\log d$) was achieved. Thus, the particles released were at the higher end of the accumulation mode (2 to 2.5 μm in diameter) and in the lower tail of the coarse particle mode ($> 2.5 \mu\text{m}$). For the other two powders, and for particles in the size range of 0.5 to 3 μm , concentrations ranged from approximately 100 to 1500 cm^3 . The concentration from the sunscreen powder was the highest over this size range with the peak at approximately 2 μm . For the particle size range between 3 and 10 μm , the sunscreen powder had the highest concentration among the three investigated. Especially intriguing was the presence of released particles between 10 and 20 μm . While the nanotechnology-based powders would be expected to be very fine by definition, the individual particles form agglomerates that during powder's application were released as particles with aerodynamic diameters as large as 20 μm . In fact, as seen in Figure 2, it was evident that particles even larger than 20 μm were present, but were not registered as such due to the limitation of the measurement equipment.

By comparing the data in Figures 1 and 2, one is likely to see a discrepancy in the transition region data provided between the SMPS and APS. Since the SMPS measurements are based on the electrical properties and APS measurements are based on the aerodynamic properties of particles, the different detection principles can result in different detection efficiency in the transition size range (0.5 to 0.7 μm) depending on various aerosol characteristics.^{38,39}

The release and potential inhalation of super-coarse particles ($> 10 \mu\text{m}$ in diameter)⁴⁰ resulting from the application of nanotechnology-based cosmetic powders were significant from exposure assessment point of view. A surface area of a solid particle is proportional to its diameter squared and could be estimated with relative ease for uniformly shaped particles. However, a 20 μm agglomerate, composed of many thousands of 100 nm particles, would have a surface area hundreds of times larger compared to a solid particle of the same 20 μm and, consequently, higher potential for surface-based reactions. When agglomerates made up of nanosized particles are inhaled, the lung is challenged with particles that have a very large surface area. If negative health effects are induced via interactions with particle surface, then the nanoparticle agglomerates would present a much higher risk than the solid particles of the same size. However, the presence of large agglomerates may also stress the need to estimate exposure on a particle mass basis. As can be seen in Figure 3, which presents mass distribution data (presented as $M/\log d$, mg/m^3), for nanotechnology-based "sunscreen powder" and "skin treatment powder," the mass concentration approached or exceeded 10 mg/m^3 for particles between 2.5 and 8 μm . Due to their size, the majority of these particles would be deposited in upper airways and would be much more easily cleared from the respiratory system compared to the particles that were deposited deep in the lung. In general, for all three powders, exposure to PM_{10} particles (diameter $< 10 \mu\text{m}$) deposited in thoracic airways could be substantial over prolonged use. The same could be said about the $\text{PM}_{2.5}$ particles deposited in lower airways.

CONCLUSION FROM THE POWDER EXPERIMENTS

The preliminary data obtained here demonstrate that when nanotechnology-based cosmetic powders are used, there is a potential for inhaling airborne particles ranging in size from tens of nanometers to tens of micrometers. Due to such a wide size range, inhaled particles would be deposited in all regions of the respiratory system: extrathoracic, thoracic, and alveolar. Since other likely routes of exposure for cosmetic powders include dermal and ingestive, studies should also be performed to estimate exposure via these routes.

Step 4. Analysis of the duration and intensity of activities

The data presented in Figures 1, 2, and 3 clearly show that particles ranging in size from 10 nm to 20 μm and potentially larger are released and could be inhaled during the application of cosmetic powders. Such potential for exposures to a large segment of the population demonstrates that there is an urgent need for more thorough investigation of different powder types, as well as the frequency and duration of their application. The frequency and duration of application as well as changes in particle size distributions may vary substantially among different users, such as an occasional user compared to a stage performer. All these factors will affect the location of particle deposition and their clearance from the respiratory system. The same factors will affect the reaction of agglomerates to the forces that govern particle clearance or transport deeper into the respiratory system or even into the blood stream. Ultimately, these processes will affect the magnitude of any health risk that could be associated with the use of nanotechnology-based cosmetic powders.

Step 5: Analysis of bioaccessibility of nanoparticles in both the lungs and digestive system(that is, the potential of particles to interact with the biological tissue) will be carried out in later studies.

CONCLUSION

The discussion presented above illustrates the gaps in our understanding of human exposures to nanoparticles stemming from the use of nanotechnology-based consumer products. A series of steps that could be taken to characterize such exposures have been suggested. One of the key steps is the simulation of realistic product use and exposure patterns for different classes and types of consumer products that use nanotechnology. Our preliminary studies with nanotechnology-based cosmetic powders clearly illustrate that the use of such products could result in inhalation exposures to particles of a very broad size range, which will result in particle deposition in all regions of the respiratory system. In addition to individual nanosized particles, the deposited particles are likely to include the agglomerates of nanoparticles with large surface areas and high mass concentrations. Given the wide and ever-increasing availability of nanotechnology-based consumer products and the size of the potentially exposed population, it is imperative that we improve our understanding of human exposure, and then complete accompanying studies that examine human exposure-response relationships.

Acknowledgments

The work of the first author was sponsored by Robert Wood Johnson Medical School (RWJMS)-University of Medicine and Dentistry of New Jersey (UMDNJ), and Rutgers University. This research was supported in part by funding from the National Institute of Environmental Health Sciences (NIEHS)-sponsored UMDNJ Center for Environmental Exposures and Disease (CEED), grant number NIEHS P30ES005022.

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Figure 1.

—Size distribution of airborne cosmetic powders as measured by the scanning mobility particle sizer (SMPS), 0.014–0.7 μm size range. The data represent averages of three repeats.

Figure 2.

— Size distribution of airborne cosmetic powders as measured by the aerodynamic particle sizer (APS), 0.5–20 μm size range. The data represent averages of three repeats.

Figure 3.

—Mass distribution of airborne cosmetic powders as measured by the aerodynamic particle sizer (APS), 0.5–20 μm size range. The data represent averages of three repeats.

Table 1
Exposure Assessment Steps for Consumer Products

Step 1	Step 2	Step 3	Step 4	Step 5
Classification of the nanotechnology-based consumer products	Design of studies that simulate exposure for realistic patterns of use and types of products	Characterization of the particle release during the product use	Analysis of the duration and intensity of activities during release	Analysis of bio-accessibility of nano-particles in both the lungs and digestive system

TABLE 2
Suggested Additional Categories to Classify Nanoparticle-Containing Consumer Products

Product Type	Exposure Routes, in Order of Likelihood	Population with Likeliest Exposures	Anticipated Frequency of Use	Anticipated Duration of Each Application/Use
Cosmetic powders	Dermal, inhalation, ingestion	Females	1–2 per day	Hours for dermal; minutes for inhalation and ingestion
Sprays	Inhalation dermal, ingestion	Females, males	2–3 per week	Hours for dermal; minutes for inhalation and ingestion
Clothing	Dermal, inhalation	Females, males	Daily	Hours