Importance of Nanosafety in Engineering Education

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ABSTRACT

Nanotechnology and nanoeducation have been very important subjects in all over the world. However, the recent studies shows that nanomaterials in different surface area, size, shape, surface charge and compound interact with human and animal cells or organs, and damage or kill those cells or organs, block blood flow, and cause serious illnesses. When we understand their causes and mechanisms, more likely we will find cures for these deadly diseases associated with nanomaterials. There are a number of protection methods to manufacture non-toxic nanomaterials and devices. In the present study, we will report those nanomaterials and protection methods in detail, and give the recent developments in the field, which may be useful for the protection of students who will be working in the field.

Keywords: Nanomaterials, toxicity, protection and future directions.

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1. INTRODUCTION

For over a decade, nanotechnology is one of the fastest growing fields. It is basically fabrication, manipulation, and characterization of materials at the nanoscale (usually between 1 and 100 nm), which will significantly affect economic, educational, and social developments in all areas, such as engineering, science, defense, biomedical and biology [1]. It is also one of the leading technologies for educational revolution in the new millennium. Nanotechnology education is being offered by many universities around the globe for the integration of all engineering and science courses for the future generation [1]. Several nanotechnology programs and centers in the U.S. have been undertaken by the government and by private sectors to intensify the teaching, research, and development in nanotechnology. It is reported that development in nanotechnology will change the traditional practices of design, analysis, simulation, and manufacturing for new engineering products. Therefore, it becomes a challenge for the academic community to educate undergraduate engineering and science students with all the necessary information and leadership in this emerging field [1].

There are a number of nanoscale materials, such as nanoparticles, nanotubes, nanofibers, nanocomposites and nanofilms that are all considered next generation of materials for faster cars and planes, more powerful computers and satellites, and better microchips and batteries because of their outstanding mechanical, magnetic, electrical, optical and thermal properties. Table 1 gives the classification of nanomaterials with regard to different parameters [2]. Nanomaterials can also be used to make artificial muscle, military armors and medicines. Nanomaterials are already found in more than 600 different products, including bacterial free cloths, concretes, sunscreens, car bumpers, tooth pastes, polymeric coatings, tennis rackets, wrinkle-resistant clothes and other optical, electronic, diagnostic and sensing devices [3,4]. Figure 1 shows the various applications of nanomaterials [5].

Table 1: Classification of nanomaterials with regard to different parameters.

Classification	**Examples**
Dimension	
3 dimensions < 100nm	Particles, quantum dots, hollow spheres, etc.
2 dimensions < 100nm	Tubes, fibers, wires, platelets, etc.
1 dimension < 100nm	Films, coatings, multilayer, etc.
Phase composition	
Single-phase solids	Crystalline, amorphous particles and layers, etc.
Multi-phase solids	Matrix composites, coated particles, etc.
Multi-phase systems	Colloids, aerogels, ferrofluids, etc.
Manufacturing process	
Gas phase reaction	Flame synthesis, condensation, CVD, PVD, etc.
Liquid phase reaction	Sol-gel, precipitation, hydrothermal processing, etc.
Mechanical procedures	Ball milling, plastic deformation, etc.

Recently, it was determined that the nanomaterials could appear in air, water, soils, plants and subsequently in human and animal bodies, so they are resulted in public debate on toxicological and environmental effects of direct and indirect exposure to these nanomaterials. The risks of toxicity associated with nanomaterials can arise during the fabrications, transportation, handling, usage, waste disposal and recycling. Nanomaterials can get into human body by various routes, such as inhalation, ingestion (Figure 2), or contact through skin and persist in the system longer time based on the chemical structures [2]. Thus, sseveral sicknesses can be expected from the nanomaterials, including asthma, bronchitis, lung and liver cancer, parkinson and alzheimer, crohn`s disease, heart disease, and colon cancer [7,8].

Figure 1: Nanomaterials in different products that are used in daily life.

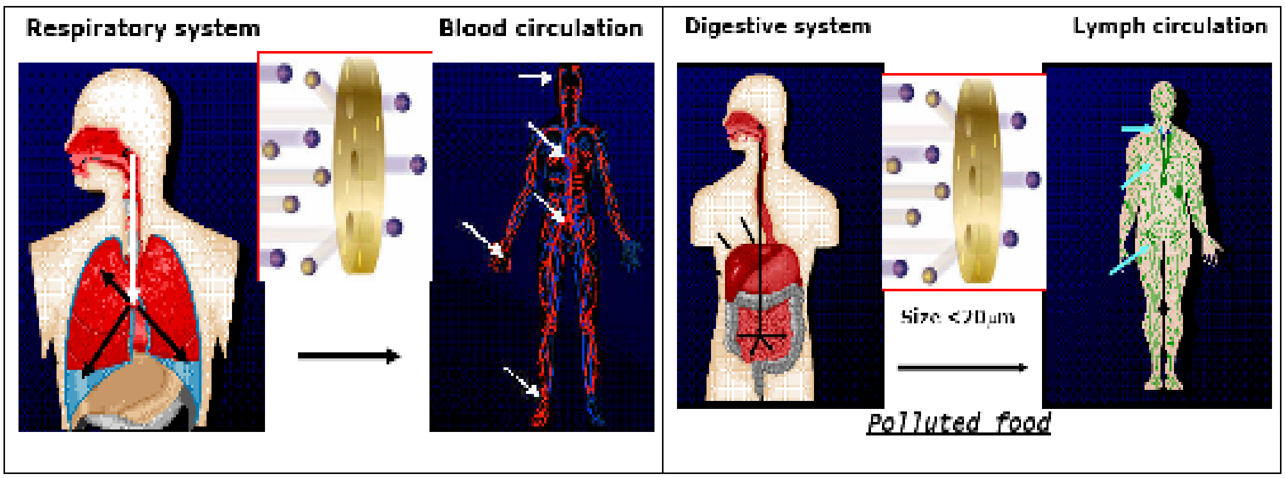

Figure 2: The entrance of various nanoparticles into human body.

2. SURFACE PROPERTIS OF NANOMATERIALS

The surface chemistry (e.g., surface potential, particle size and surface area) are the dominating factors for the toxicity of nanomaterials. These materials can react with the body, stay inert, and/or interact with the system based on their surface properties [2]. Some of the properties of nanoparticles are summarized below:

2.1 Particle size

It is stated that almost all properties of nanoparticles are different than their bulk size counterparts. Since the properties are entirely different, toxicity of the nanomaterials could be different, too [2]. The previous studies show that the smaller the particle size, the higher the toxicity is. It will be harder to remove nanoparticles from the body than larger particles. Recent toxicological studies also demonstrated that particles less than 100 nm induce toxicity in cellcultured models, as well as animal models [6,7]. Figure 3 shows the nanoparticles affecting the organs [3].

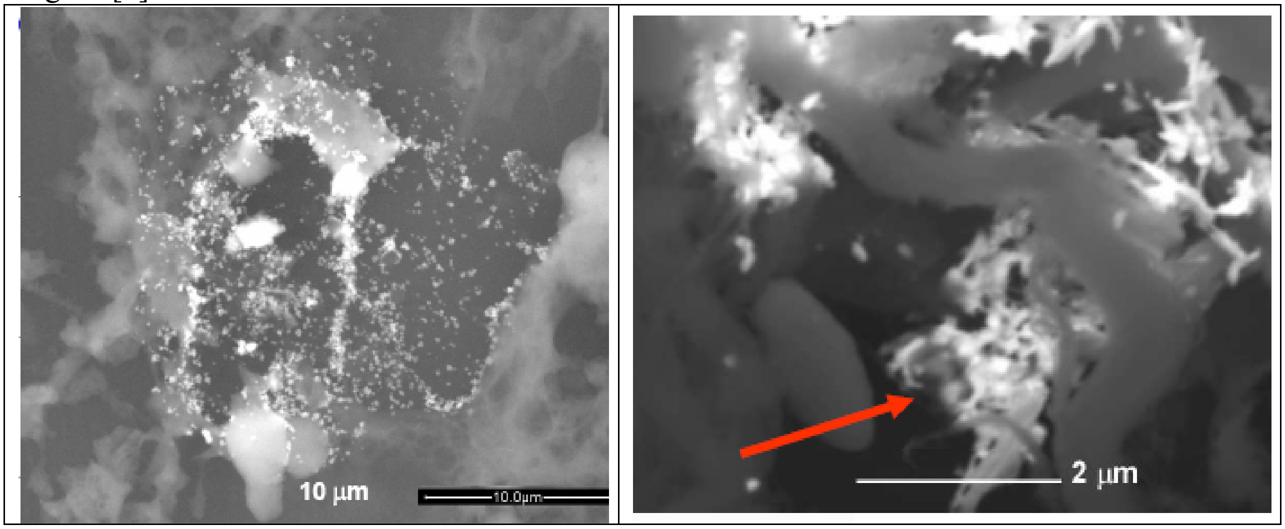

Figure 3: The images showing the lead nanoparticles in lung (left) and silver-magnesium nanoparticles in a colon cancer.

2.2 Surface Area

Surface area plays one of the major roles in the interaction of the materials with cells. One must realize that nanomaterials have a high surface-area-to-volume ratio, and thus are more reactive than their counterparts. For instance, gold, silver and platinum are chemically inactive and usually don't directly interact with the body at bulk scale. Nevertheless, at nanoscale, the surface of these nanomaterials can be chemically activated to harm the cells or organs because of the size effects [2,7].

2.3 Surface Charge

Particle agglomeration, stability and distribution can be related the surface charge and zeta potential values of nanoparticles in a liquid media. The surface charge mainly regulates the stability of the nanoparticles [7]. At lower surface charges, the nanoparticles tend to agglomerate and make a cluster. It was reported that the toxicity of single particles is a lot higher than that of aggregated nanoparticles [2].

2.4 Surface Treatment

The toxicity of the nanomaterials can be minimized using different chemical processes, such as surface treatment, modification and functionalization. An organ exposed by nanoparticles was analyzed and the results indicated that the smaller particles diffused into respiratory system faster [1]. It was also found that the nanoparticle penetrate into cells and transcytosis across epithelial and endothelial cells and lymph circulation to reach very sensitive parts of body, such as nervous system, bone marrow, brain, lymph nodes, spleen, and heart. The study concluded that surface coating and in vivo surface modification could reduce the side effects of nanoparticles [6,7].

3. CARBON BASED NANOMATERIALS

Carbon-based nanomaterials (CBN) in different forms of fullerenes, single- and multi wall carbon nanotubes (SWCNT and MWCNT), carbon nanoparticles and nanofibers are being used in a number of different applications [2]. Shapes of CBN are important factor in toxicity. Some of the CBNs have the structural similarity to asbestos, raising concerns that widespread use of carbon nanotubes may lead to mesothelioma, cancer of the lining of the lungs caused by exposure to asbestos. Especially, the needle-like fiber shapes of CNTs are more toxic than other CBNs to human skin fibroblasts and other organs. MWCNTs and SWCNTs have strong chemical stability, and when inhaled, they may not be easily dissolved in the body, which in turn could damage the cells, DNA and surrounding tissues in the long term. Generally, SWCNTs are more toxic than MWCNTs. Recent studies confirmed that the sidewall functionalized both MWCNTs and SWCNTs were less toxic to human cells than those without functionalized ones. Also, it is very interesting that CNTs synthesized by catalytic chemical vapor deposition are not toxic to human umbilical vein endothelial cells [7,8]. As a result, shape, structure, production method and functionalization are very critical parameters in toxicity of carbon based nanomaterials.

4. PROTECTION METHODS OF NANOMATERIALS

As is stated, nanomaterials can enter the body during production, handling, packaging, transportation, maintenance, and cleanup activities through inhalation, ingestion and dermal exposure. Hazard reduction of nanomaterials is necessary for the students/engineers working on production and processing of nanomaterials, as well as consumers in contact with commercial products [1,9]. Table 2 gives the hierarchy of the exposure controls of nanomaterials [10]. Some of the protection methods (Figure 4) during the production and use of nanomaterials are also given below [1]:

Table 2: The hierarchy of exposure controls of nanomaterials.

Control method	Process, equipment, or job task
1. Elimination	Change design to eliminate hazard
2. Substitution	Replace a high hazard for a low hazard
3. Engineering	Isolation/enclosure, ventilation (local, general)
4. Administrative	Procedures, policies, shift design
5. Personal protective equipment	Respirators, clothing, gloves, goggles, ear plugs

*Control methods are typically implemented in this order to limit worker exposures to an acceptable concentration (e.g., occupational exposure limit or other pre-established limit).

Sources: Plog et al. 2002; NIOSH 1990.

- Students, workers, engineers and scientist who are working on nanomaterials and devices are recommended to wear a disposable, typically plastic, body covering over their work clothes during high exposure activities and wear long gloves pulled over sleeves to minimize wrist exposure. Other recommendations can be antistatic shoes to prevent ignition by static charges, sticky mats at laboratory entrances to prevent accidental nanomaterials transfers in and out.

- Hazardous effects of nanomaterials needs to be reduced during the production and processing. The waste of nanomaterials should be limited. Outputs are sometimes more hazardous than products or wastes from such activities.
- Students who inhaled nanomaterials are advised to consume milk and unrefined sugar to reduce the toxicity level of nanomaterials.
- Nitrile gloves or wrist length disposable nitrile gloves with extended sleeves must be worn during the handling of nanomaterials (Figure 4). The gloves need to be changed very often.
- For eye protection, safety glasses with side shields must be on the face during the use of nanomaterials in the forms of solids, liquids and aerosols.
- Volumes of the liquid based nanomaterials must be limited to the milliliter range (<200 ml) in a sealed container when not in use.
- Total particle masses must be limited to the milligram range (<200 mg) and be manipulated within a high efficient particulate air (HEPA) filtered laboratory exhaust hood over water soaked absorbent paper to capture any spilled materials
- Containers of nanomaterials must be labeled with a sign on “NANOMATERIALS”.
- Nanomaterials are considered hazardous materials, so students should take all the safety rules necessary in the field/laboratory.

Figure 4: The photographs showing the simple protection methods for the potentially hazardous engineered nanomaterials.

In addition to these, National Institute for Occupational Safety and Health (NIOSH) has sequential steps for the students, workers and engineers who are involved in nanotechnology related research and development. These steps given in Figure 5 will potentially reduce the risk of exposing nanomaterials to them [1,10].

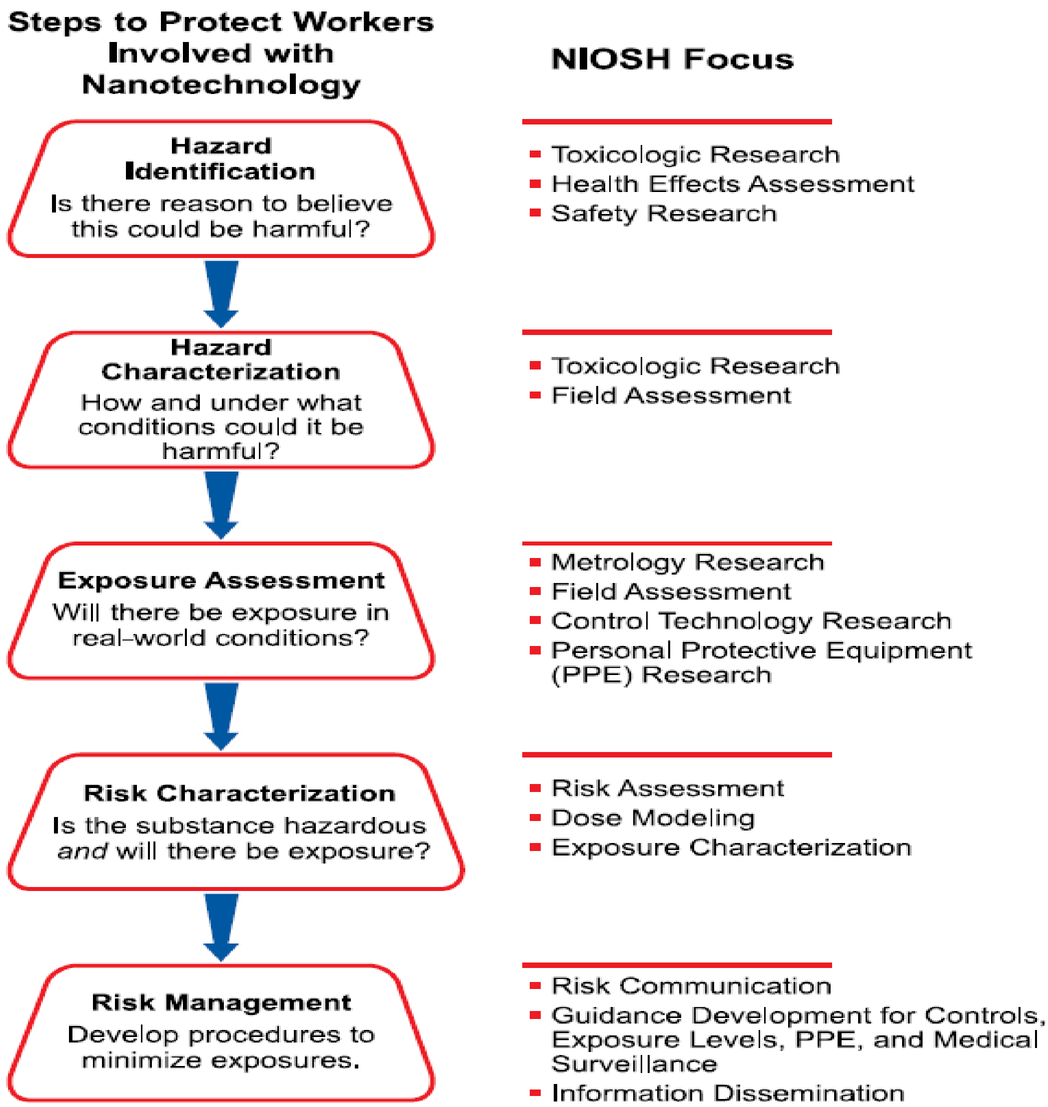

Figure 5: Steps of NIOSH for the workers/students involved in nanotechnology.

5. CONCLUSION

Nanotechnology has been growing drastically for more than 10 years, so nanosafety is an important part of nanoeducation for future engineers. Nanomaterials have superior properties for various applications, but they can be very dangerous if not properly handled. Thus, students who are working in this field should take all the necessary rules to protect themselves during the production and handling of nanomaterials.

REFERENCES

1. Asmatulu, R., Khan, W., Nguyen, K.D., and Yildirim, M.B. "Synthesizing Magnetic Nanocomposite Fibers for Undergraduate Nanotechnology Laboratory," *International Journal of Mechanical Engineering Education* (in press).
2. Asmatulu, R., Asmatulu, E. and Yourdkhani, A. "Toxicity of Nanomaterials and Recent Developments in the Protection Methods," SAMPE Fall Technical Conference, Wichita, October 19-22, 2009, pp. 1-12.
3. Asmatulu, R. "Introduction to Nanotechnology – Class Notes," Wichita State University, 2008.
4. Cao, G. "Nanostructures and Nanomaterials, Synthesis, Properties and Applications," Imperial College Press, 2004.
5. http://www.npr.org/templates/story/story.php?storyId=5257306, accessed in 6/17/2009.
6. Asmatulu, R. "Biomaterials – Class Notes," Wichita State University, 2008.
7. Kumar, C. "Nanomaterials- Toxicity, Health and Environmental Issues," WILEY-VCH., 2006.
8. Karakoti, A.S., Hench, L.L. and Seal, S. "The Potential Toxicity of Nanomaterials — the Role of Surfaces," *JOM Journal of the Minerals*, Metals and Materials Society, 58 (2006) pp. 77-82.
9. Maynard, A.D. "Safe Handling of Nanotechnology" *NATURE*, Vol. 444, 2006, pp. 267-269.
10. http://www.cdc.gov/niosh/topics/nanotech/safenano/, accessed in 6/15/2009.