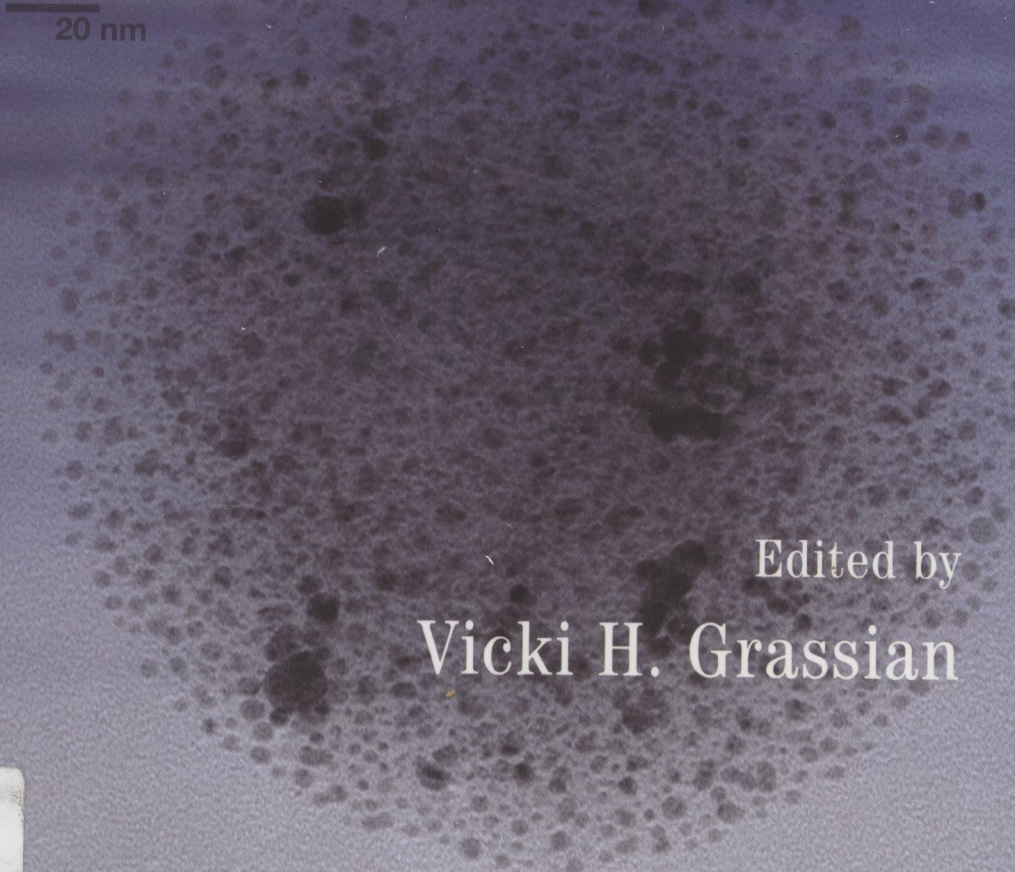
NANOSCIENCE and NANOTECHNOLOGY

Environmental and Health Impacts



Edited by

Vicki H. Grassian

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NANOSCIENCE AND NANOTECHNOLOGY

To my family

PREFACE

Nanoscience is the study of the fundamental principles of molecules and structures with at least one dimension between 1 and 100 nm. **Nanotechnology** is the application of these nanostructures into useful nanoscale devices.

BACKGROUND

The ability to manipulate and fabricate matter on the nanometer length scale is far better than ever before, with new capabilities to prepare and synthesize highly uniform nanoscale materials, and the advent of new instrumentation to investigate nanoscale materials. On the nanometer length scale, properties of matter can substantially differ and can exhibit size-dependent behavior. With these properties, a host of new materials have now become available for energy and environmental applications, and for improving human health (e.g., for disease detection, drug delivery, etc.).

The properties of matter depend on chemical composition and phase, and on the nanoscale the properties of matter also depend on size. On the nanoscale, electronic, optical, and magnetic properties can be size dependent. In addition, because of the high surface/volume ratio, surface properties, surface free energies, and surface coatings will also change the properties of nanomaterials. Given that on the nanoscale, the properties of matter depend on size, it can be asked, how well do we understand the environmental health and safety risks of nanomaterials? For example, can material safety data sheets developed for bulk graphite be used for nano-based carbon materials such as carbon nanotubes or buckyballs? What necessary measures are needed to ensure that the implications of nanomaterials are well understood as these materials are developed and used in a wide range of applications? Furthermore, what can be done to reduce the uncertainties in our understanding of the environmental health and safety implications of nanotechnology?

In the United States, the Environmental Protection Agency (EPA) provides funds not only for cleanup at superfund sites but also for superfund centers to provide a scientific basis for understanding toxicological impacts of these sites. A much better approach for future technologies is to fund centers for the study of environmental implications as technologies are developed. This new paradigm of doing business for the U.S. EPA is evident in the recent plan to partner with the National Science Foundation to fund a national center for the environmental implications of nanomaterials. In addition to a national center, there are several current funding initiatives that support the efforts of individual researchers and small research teams through several

federal funding agencies in the United States, Canada, Europe, Australia, and other nations. In the United States, these include the Environmental Protection Agency and National Science Foundation, as noted above, as well as the National Institute of Environmental Health Science and the National Institute of Occupational Safety and Health. This represents a new paradigm for balancing technology development with environmental health and safety concerns.

The ultimate goal of the research activities discussed in each of the chapters of this book is to provide a strong scientific basis to the understanding of the environmental health and safety of nanomaterials. A high level of scientific understanding is essential so that sound environmental policies, if needed, can be developed and implemented with certainty while nanoscience and nanotechnology continue to grow. The avoidance of environmental health and safety problems, such as those that occurred with the development and use of chlorofluorocarbons (CFCs), polychlorinated biphenyls (PCBs), asbestos, and others, is imperative. In addition, from an economic standpoint even the avoidance of perceived risks is essential if nanotechnologies are to be accepted by the public. So from many perspectives—Occupational Health: Will this be the next asbestos? Environmental Health: Will this be the next PCB or CFC? Manufacturing/Marketing: Will this be the next genetically modified foods?—it is critical that issues related to the environmental and health impacts of nanomaterials be evaluated and understood.

OVERVIEW OF BOOK

Nanomaterials are of varying chemical complexity (bulk and surface), size, shape, and phase. Therefore, there exist large challenges in understanding the environmental health and safety of nanomaterials, and truly interdisciplinary efforts are needed. This book reflects the interdisciplinary nature of the research on the environmental and health impacts of nanoscience and nanotechnology. Chapter authors come from a variety of disciplines including chemical engineering, chemistry, civil and environmental engineering, environmental microbiology, geoscience, occupational and environmental health, pathology, pharmacology, and plant and soil science. The research described herein represents a compilation of some of the most recent studies and the current state of the science of the environmental and health impacts of nanoscience and nanotechnology. The book is divided into three parts as shown below.

PART I ENVIRONMENTAL AND HEALTH IMPACTS OF NANOMATERIALS: OVERVIEW AND CHALLENGES

Part I consists of three chapters: *Nanomaterials and the Environment* discusses the different types of nanomaterials that are being commercially produced and the potential for these materials to get into the environment; *Assessing the Life Cycle Environmental Implications of Nanomanufacturing: Opportunities and Challenges*

discusses different approaches toward life cycle assessment that are being explored, as well as the difficulties; and the last chapter of this part, *An Integrated Approach Toward Understanding the Environmental Fate, Transport, Toxicity, and Health Hazards of Nanomaterials*, focuses on the importance and need to integrate high-quality nanomaterial characterization with studies related to the environmental health and safety of these materials and shows examples of different techniques that can be used for nanomaterials' physicochemical characterization.

PART II FATE AND TRANSPORT OF NANOMATERIALS IN THE ENVIRONMENT

Part II focuses on what happens to nanomaterials once they get into the environment. Six chapters cover this topic with an emphasis on water and soil environments. Three of the chapters focus on metal and metal oxide nanomaterials. These include *Properties of Commercial Nanoparticles that Affect Their Removal During Water Treatment*; *Transport and Retention of Nanomaterials in Porous Media*; and *Transport of Nanomaterials in Unsaturated Porous Media*. Two chapters focus on carbon-based nanomaterials: *Surface Oxides on Carbon Nanotubes (CNTs): Effects on CNT Stability and Sorption Properties in Aquatic Environments* and *Chemical and Photochemical Reactivity of Fullerenes in the Aqueous Phase*. The last chapter of this part, *Bacterial Interactions with CdSe Quantum Dots and Environmental Implications*, looks at a different class of nanomaterials, crystalline semiconductor quantum dots, and their interactions with bacteria.

PART III TOXICITY AND HEALTH HAZARDS OF NANOMATERIALS

Part III contains eight chapters on the toxicity and health hazards of nanomaterials. This part focuses on the impact nanomaterials have on the environment and its encompassing biota. Investigations described in Part III focus on living systems at all scales, from biological components to cells to simple organisms to fish to animals to humans. The first chapter in this part, *Potential Toxicity of Fullerenes and Molecular Modeling of Their Transport Across Lipid Membranes*, focuses on toxicity of fullerenes, C_{60}, and the transport of these nanomaterials across membranes. The next two chapters focus on *in vitro* studies and include *In Vitro Models for Nanoparticle Toxicology* and *Biological Activity of Mineral Fibers and Carbon Particulates: Implications for Nanoparticle Toxicity and the Role of Surface Chemistry*. The next two chapters in this part investigate environmental health and safety from an organism perspective. Chapter 13, *Growth and Some Enzymatic Responses of E. coli to Photocatalytic TiO_2*, examines the response of *E. coli* in the presence of illuminated TiO_2 nanoparticles and Chapter 14, *Bioavailability, Trophic Transfer, and Toxicity of Manufactured Metal and Metal Oxide Nanoparticles in Terrestrial Environments*, focuses on bioaccumulation and trophic transfer of metal and metal oxide nanoparticles.

The next two chapters of Part III focus on issues related to the toxicity of inhaled nanomaterials and the impact on human health. *Health Effects of Inhaled Engineered Nanoscale Materials* and *Neurotoxicity of Manufactured Nanoparticles* examine the multitude of potential health risks that result from inhalation of nanomaterials. Since there are concerns that inhalation exposure may be particularly problematic for those working in the industry, the last chapter, *Occupational Health Hazards of Nanoparticles*, focuses on this concern.

FUTURE OUTLOOK

The development of nanotechnology-based consumer products is predicted to grow substantially in the next 10 years and beyond. Along with this growth, it is clear that there will be many issues and questions that need to be addressed related to the potential impact this technology will have on the environment, living organisms, and human health. We hope that this book inspires some readers to rise to the challenges that are faced so that the environmental and health impacts of nanoscience and nanotechnology can be understood and therefore properly controlled as new commercial uses and applications emerge.

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