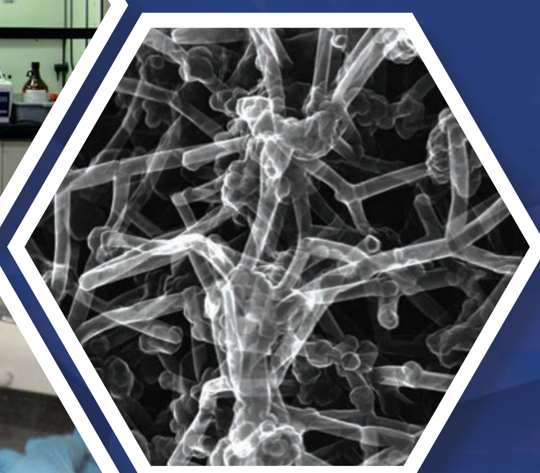
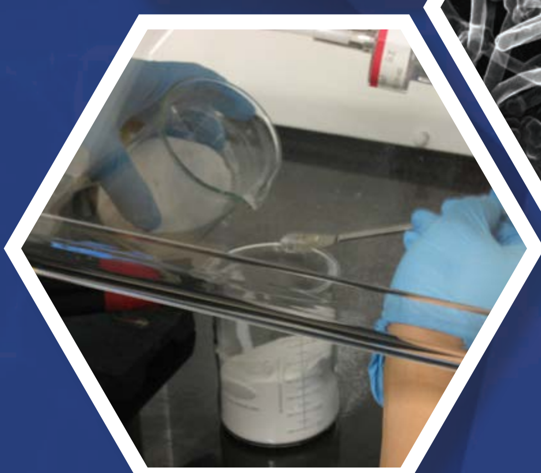
General Safe Practices for Working with Engineered Nanomaterials in Research Laboratories





DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

CDC Workplace Safety and Health

NIOSH

Center for High-rate Nanomanufacturing

PAGE LEFT INTENTIONALLY BLANK

General Safe Practices for Working with Engineered Nanomaterials in Research Laboratories

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Disclaimer

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (NIOSH). In addition, citations to Web sites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these Web sites. All Web addresses referenced in this document were accessible as of the publication date.

Ordering Information

To receive documents or other information about occupational safety and health topics, contact NIOSH at

Telephone: **1–800–CDC–INFO** (1–800–232–4636)
TTY: 1–888–232–6348
E-mail: cdcinfo@cdc.gov

or visit the NIOSH Web site at **www.cdc.gov/niosh**.

For a monthly update on news at NIOSH, subscribe to *NIOSH eNews* by visiting **www.cdc.gov/niosh/eNews**.

DHHS (NIOSH) Publication No. 2012–147

May 2012

SAFER • HEALTHIER • PEOPLE™

Foreword

The National Institute for Occupational Safety and Health (NIOSH) is pleased to present *General Safe Practices for Working with Engineered Nanomaterials in Research Laboratories.* Engineered nanomaterial applications are rapidly expanding throughout the United States and worldwide. The research community is at the front line of creating these new nanomaterials, testing their usefulness in a variety of applications, and determining their toxicological and environmental impacts.

With the publication of this document, NIOSH hopes to raise awareness of the occupational safety and health practices that should be followed during the synthesis, characterization, and experimentation with engineered nanomaterials in a laboratory setting. The document contains recommendations on engineering controls and safe practices for handling engineered nanomaterials in laboratories and some pilot scale operations. This guidance was designed to be used in tandem with well-established practices and the laboratory's chemical hygiene plan. As our knowledge of nanotechnology increases, so too will our efforts to provide additional guidance materials for working safely with engineered nanomaterials.

/s
John Howard, M.D.
Director, National Institute for
Occupational Safety and Health
Centers for Disease Control and Prevention

PAGE LEFT INTENTIONALLY BLANK

Acknowledgments

This document is based on input from several subject matter experts and was initiated as a joint effort under a Memorandum of Understanding between NIOSH and the Center for High-rate Nanomanufacturing (CHN). Some of the specific content was derived from a report generated by Michael Ellenbecker and Su-Jung (Candace) Tsai at the University of Massachusetts Lowell (UMass Lowell), one of the CHN member campuses, and was supported by a contract from the NIOSH Nanotechnology Research Center (NTRC). Paul Schulte is the manager and Charles Geraci is the coordinator of the NIOSH nanotechnology cross-sector program. Special thanks go to Catherine Beaucham and Laura Hodson for writing and organizing this report. Others who contributed substantially to the writing and research include Mark Hoover and Ralph Zumwalde.

The NIOSH NTRC also acknowledges the contributions of Gino Fazio for desktop publishing and graphic design, Michael Elliot and Terri Pearce for review, and John Lechliter and Seleen Collins for editing the report. Photographs are courtesy of Catherine Beaucham and Mark Methner of NIOSH, Michael Ellenbecker and Su-Jung (Candace) Tsai of UMass Lowell and Mia Ertas of the University of Albany College of Nanoscale Science & Engineering (CNSE).

External Expert Peer Review

Lawrence M. Gibbs, MPH, CIH
Associate Vice Provost for EH&S
Stanford University

Bruce C. Stockmeier, CIH
ES&H Coordinator
Argonne National Laboratory
Center for Nanoscale Materials

William Kojola
Industrial Hygienist
The American Federation of Labor—Congress of Industrial Organizations (AFL-CIO)

FuAnjali Lamba, MPH, CIH
Senior Industrial Hygienist
Chemical Engineering Branch
Office of Pollution Prevention and Toxics
U.S. Environmental Protection Agency

PAGE LEFT INTENTIONALLY BLANK

Executive Summary

Nanotechnology, the manipulation of matter at a nanometer scale to produce new materials, structures, and devices having new properties, may revolutionize life in the future. It has the potential to impact medicine through improved disease diagnosis and treatment technologies and to impact manufacturing by creating smaller, lighter, stronger, and more efficient products. Nanotechnology could potentially decrease the impact of pollution by improving methods for water purification or energy conservation. Although engineered nanomaterials present seemingly limitless possibilities, they bring with them new challenges for identifying and controlling potential safety and health risks to workers. Of particular concern is the growing body of evidence that occupational exposure to some engineered nanomaterials can cause adverse health effects.

As with any new technology or new material, the earliest exposures will likely occur for those workers conducting discovery research in laboratories or developing production processes in pilot plants. The research community is at the front line of creating new nanomaterials, testing their usefulness in a variety of applications and determining their toxicological and environmental impacts. Researchers handling engineered nanomaterials in laboratories should perform that work in a manner that protects their safety and health. This guidance document provides the best information currently available on engineering controls and safe work practices to be followed when working with engineered nanomaterials in research laboratories.

Risk Management

Risk management is an integral part of occupational health and safety. Potential exposures to nanomaterials can be controlled in research laboratories through a flexible and adaptive risk management program. An effective program provides the framework to anticipate the emergence of this technology into laboratory settings, recognize the potential hazards, evaluate the exposure to the nanomaterial, develop controls to prevent or minimize exposure, and confirm the effectiveness of those controls.

Hazard Identification

Experimental animal studies indicate that potentially adverse health effects may result from exposure to nanomaterials. Experimental studies in rodents and cell cultures have shown that the toxicity of ultrafine particles or nanoparticles is greater than the toxicity of the same mass of larger particles of similar chemical composition.

Research demonstrates that inhalation is a significant route of exposure for nanomaterials. Evidence from animal studies indicates that inhaled nanoparticles may deposit deep in lung tissue, possibly interfering with lung function. It is also theorized that nanoparticles may enter the bloodstream through the lungs and transfer to other organs. Dermal exposure and subsequent penetration of nanomaterials may cause local or systemic effects. Ingestion is a third potential route of exposure. Little is known about the possible adverse effects of ingestion of nanomaterials, although some evidence suggests that nanosized particles can be transferred across the intestinal wall.

Exposure Assessment

Exposure assessment is a key element of an effective risk management program. The exposure assessment should identify tasks that contribute to nanomaterial exposure and the workers conducting those tasks. An inventory of tasks should be developed that includes information on the duration and frequency of tasks that may result in exposure, along with the quantity of the material being handled, dustiness of the nanomaterial, and its physical form. A thorough understanding of the exposure potential will guide exposure assessment measurements, which will help determine the type of controls required for exposure mitigation.

Exposure Control

Exposure control is the use of a set of tools or strategies for decreasing or eliminating worker exposure to a particular agent. Exposure control consists of a standardized hierarchy to include (in priority order): elimination, substitution, isolation, engineering controls, administrative controls, or if no other option is available, personal protective equipment (PPE).

Substitution or elimination is not often feasible for workers performing research with nanomaterials; however, it may be possible to change some aspects of the physical form of the nanomaterial or the process in a way that reduces nanomaterial release.

Isolation includes the physical separation and containment of a process or piece of equipment, either by placing it in an area separate from the worker or by putting it within an enclosure that contains any nanomaterials that might be released.

Engineering controls include any physical change to the process that reduces emissions or exposure to the material being contained or controlled. Ventilation is a form of engineering control that can be used to reduce occupational exposures to airborne particulates. General exhaust ventilation (GEV), also known as dilution ventilation, permits the release of the contaminant into the workplace air and then dilutes the concentration to an acceptable level. GEV alone is not an appropriate control for engineered nanomaterials or any other uncharacterized new chemical entity. Local exhaust ventilation (LEV), such as the standard laboratory chemical hood (formerly known as a laboratory fume hood), captures emissions at the source and thereby removes contaminants from the immediate occupational environment. Using selected forms of LEV properly is appropriate for control of engineered nanomaterials.

Administrative controls can limit workers' exposures through techniques such as using job-rotation schedules that reduce the time an individual is exposed to a substance. Administrative controls may consist of standard operating procedures, general or specialized housekeeping procedures, spill prevention and control, and proper labeling and storage of nanomaterials. Employee training on the appropriate use and handling of nanomaterials is also an important administrative function.

PPE creates a barrier between the worker and nanomaterials in order to reduce exposures. PPE may include laboratory coats, impervious clothing, closed-toe shoes, long pants, safety glasses, face shields, impervious gloves, and respirators.

Other Considerations

Control verification or confirmation is essential to ensure that the implemented tools or strategies are performing as specified. Control verification can be performed with traditional industrial hygiene sampling methods, including area sampling, personal sampling, and real-time measurements. Control verification may also be achieved by monitoring the performance parameters of the control device to ensure that design and performance criteria are met.

Other important considerations for effective risk management of nanomaterial exposure include fire and explosion control. Some studies indicate that nanomaterials may be more prone to explosion and combustion than an equivalent mass concentration of larger particles.

Occupational health surveillance is used to identify possible injuries and illnesses and is recommended as a key element in an effective risk management program. Basic medical screening is prudent and should be conducted under the oversight of a qualified healthcare professional.

PAGE LEFT INTENTIONALLY BLANK

Contents

Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienist
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BSC	biological safety cabinet
CFR	Code of Federal Regulations
CHN	Center for High-rate Nanomanufacturing
CNT	carbon nanotube
DNA	deoxyribonucleic acid
FLAR	flame aerosol reactor
FSP	flame spray pyrolysis
GEV	general exhaust ventilation
HEPA	high-efficiency particulate air
HVAC	heating, ventilation, and air conditioning
ICRP	International Commission on Radiological Protection
ISO	International Organization for Standardization
LEV	local exhaust ventilation
LLNL	Lawrence Livermore National Laboratory
µm	micrometer
MWCNT	multi-walled carbon nanotube
nm	nanometer
NAS	National Academy of Sciences
NIOSH	National Institute for Occupational Safety and Health
NTRC	Nanotechnology Research Center
OPC	optical particle counter
OECD	Organization for Economic Co-operation and Development
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
PtD	Prevention through Design
REL	recommended exposure limit
RL	risk level
SWCNT	single-walled carbon nanotube

PAGE LEFT INTENTIONALLY BLANK

1 Introduction

According to The International Organization for Standardization Technical Committee 229 (Nanotechnologies) (ISO/TS 27687:2008), a nano-object is a material with one, two, or three external dimensions in the 1- to 100-nm size range. Nano-objects are frequently incorporated into a larger matrix known as a nanomaterial. Nanoparticles are a specific type of nano-object, with all three external dimensions at the nanoscale. An additional term, ultrafine particles, is used to describe nanometer-diameter particles that have not been intentionally produced but are the incidental products of processes [NIOSH 2009a]. For purposes of this document, the term *nanomaterial* is used to describe engineered nano-objects, including engineered nanoparticles.

Nanomaterials are increasingly being used in optoelectronic, electronic, magnetic, medical imaging, drug delivery, cosmetic, catalytic, and other applications. Although nanomaterials present seemingly limitless possibilities, they bring with them new challenges to understanding, predicting, and managing potential safety and health risks to workers. Exposures to nanomaterials can involve a wide range of nanomaterial sizes, shapes, functionalities, concentrations, chemical compositions, and exposure frequencies or durations. Researchers working with engineered nanomaterials have the potential to be exposed through a variety of sources and processes, including leaks from equipment used in the synthesis of nanomaterials, manipulating dry nanopowders, sonicating liquid suspensions, or mechanically disrupting materials containing or coated with nanomaterials [Aitken et al. 2004; Johnson et al. 2010]. A growing body of evidence indicates that exposure to some of these engineered nanomaterials can cause adverse health effects. Based on this preliminary toxicological data, prudent practice dictates controlling occupational exposure to nanomaterials.

2 Scope

As with any new technology, the earliest exposures will likely occur among those workers conducting research in laboratories and pilot plants. Researchers handling engineered nanomaterials in laboratories and pilot scale operations should perform that work in a manner that is protective of their safety and health. Although incidental nanoparticles (also known as ultrafine particles) exist in nature, the focus of this document is to provide guidance on the safe handling of purposely designed, engineered nanomaterials in research laboratories. The information may also be applicable in some pilot-scale facilities.

Research laboratories include any facility performing basic or applied research involving nanomaterials. Nanomaterial research laboratories may be housed at universities, government agencies, and private companies. Research laboratories may produce their own nanomaterials, work with nanomaterials produced by others, or some combination