

108.14 A case study on risk evaluation of printed electronics using nanosilver ink

E. Kim, J.-H. Lee, J.-K. Kim, G.-H. Lee, K. Ahn, J.-D. Park, and I.-J. Yu

With the ever-increasing development of nanotechnology, our society is being surrounded by possible risks related to exposure to manufactured nanomaterials. The consumer market already includes many products that contain silver nanoparticles (AgNPs), including various household products, such as yoga mats, cutting boards, running shirts, and socks. Plus, there is a growing concern over the release of AgNPs in workplaces related to the manufacture and application of nanomaterials. Therefore, this study investigated the release of AgNPs during the operation of a printed electronics printer. Using an exposure simulation chamber, a nanoparticle collector, SMPS (scanning mobility particle sizer), CPC (condensation particle counter), dust monitor, and MCE (mixed cellulose esters) filters are all connected to measure the AgNP exposure levels when operating a printed electronics printer. As a result, a very small amount of AgNPs was released during the operation of the printed electronics printer, plus the number of AgNPs inside the exposure simulation chamber was lower than that outside. Plus, when evaluating the potential risks for consumers and workers using a margin of exposure (MOE) approach and target MOE of 1000, the operational results far exceeded the target MOE in this simulation study and in a previous workplace exposure study. Therefore, the overall results indicate a no-risk concern level in the case of printed electronics using nanosilver ink.

108.15 Evaluation of darkfield microscopy and hyperspectral imaging for analysis of airborne carbon nanotubes captured from occupational settings

N. M. Neu-Baker, A. Eastlake, S. A. Brenner, and C. L. Geraci

Current best-known methods for engineered nanomaterial (ENM) exposure assessment in occupational environments include the capture of airborne ENMs onto filter media. The standard method for the detection of ENMs captured onto filter media is direct visualization via transmission electron microscopy (TEM) for particle sizing, count, and morphology, coupled with compositional analysis, typically by energy-dispersive spectroscopy (EDS). This method is low-throughput, expensive, and time- and resource-intensive. Enhanced darkfield microscopy (EDFM) with hyperspectral imaging (HSI) analysis is being evaluated as a high-throughput screening technique to rapidly identify filter media samples that contain ENMs of interest that may then move on for further, more intensive TEM/EDS analysis. Building upon a preliminary study lead by NIOSH, we are further exploring the use of EDFM/HSI for the rapid visualization and identification of carbon nanotubes (CNTs) captured on mixed cellulose ester (MCE) filter media. We will compare the protocol we develop for EDFM/HSI of CNTs on MCE filter media to conventional TEM methods for accuracy, reliability, and precision of this new screening method. Future directions include expanding the EDFM/HSI protocol to other ENMs and to polycarbonate (PC) filter media samples.

108.16 Information resources for exposure assessment of engineered nanomaterials

M. D. Hoover

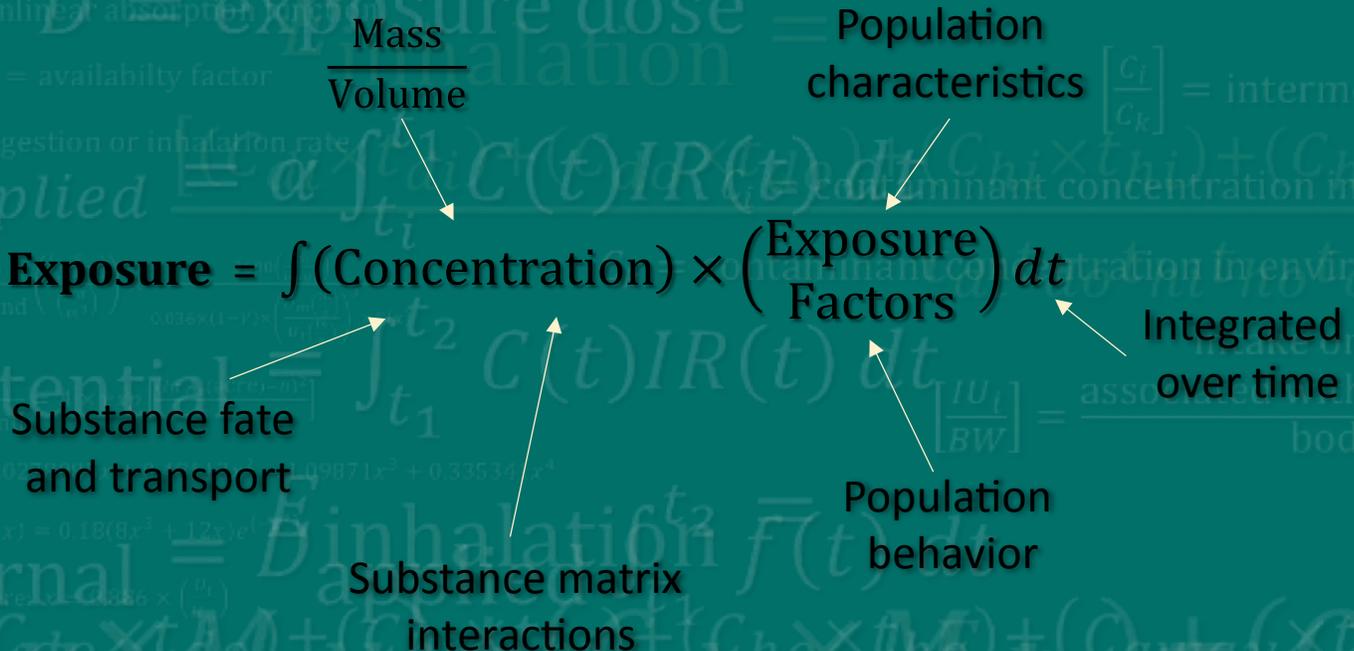
Nanoinformatics is the science and practice of determining which information is relevant to meeting the objectives of the nanoscale science and engineering community; and then developing and implementing effective mechanisms for collecting, validating, storing, sharing, analyzing, modeling, and applying that information; and then confirming that appropriate decisions were made and that desired mission outcomes were achieved as a result of that information; and finally conveying experience to the broader community, contributing to generalized knowledge, and updating standards and training. In our roles as information customers, creators, curators, and analysts, this definition should guide our collaborations to effectively assess and manage exposures to engineered nanomaterials. Key questions include: Is a hazard

Quantifying Exposure to Engineered Nanomaterials (QEEN) from Manufactured Products

Addressing Environmental, Health, and Safety Implications

Workshop Proceedings
July 7–8, 2015

Sponsored by the
Consumer Product Safety Commission
in collaboration with the
National Nanotechnology Initiative



About the National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is a U.S. Government research and development (R&D) initiative involving 20 Federal departments, independent agencies, and independent commissions working together toward the shared and challenging vision of a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society. The combined, coordinated efforts of these agencies have accelerated discovery, development, and deployment of nanotechnology to benefit agency missions in service of the broader national interest.

About the Nanoscale Science, Engineering, and Technology Subcommittee

The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee is the interagency body responsible for coordinating, planning, implementing, and reviewing the NNI. NSET is a subcommittee of the Committee on Technology (CoT) of the National Science and Technology Council (NSTC), which is one of the principal means by which the President coordinates science and technology policies across the Federal Government. The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support to the NSET Subcommittee and supports the Subcommittee in the preparation of multiagency planning, budget, and assessment documents, including this report. More information about the NSET Subcommittee, the NNI, and the NNCO can be found at nano.gov.

About the Nanotechnology Environmental and Health Implications Working Group

The NSET Subcommittee and its Nanotechnology Environmental and Health Implications (NEHI) Working Group provide leadership in establishing the NNI environmental, health, and safety (EHS) research agenda and in communicating data and information related to the EHS aspects of nanotechnology between NNI agencies and the public. Through the coordinated activities of the NSET and NEHI participating agencies, the NNI actively supports the development of the new tools and methods required for research that will enable risk analysis and assist in regulatory decision making.

About This Report

This document is the report from a workshop sponsored by the Consumer Product Safety Commission and co-hosted by the NNI that was held on July 7 and 8, 2015. The technical workshop was designed to bring together experts from Federal, regional, State, and local governmental and nongovernmental organizations to provide an assessment of the state of understanding in nanotechnology-related exposure science. The goal of this report is to provide an impactful document that will be useful in planning the future direction of exposure science and nanomaterials environmental, health, and safety research. This workshop is one of a series of technical workshops sponsored by the NSET Subcommittee to inform long-range planning efforts for the NNI and its EHS Research Strategy. This report is not a consensus document but rather a technical report with an aim to assess the state of exposure science and the tools and methods available to characterize and quantify exposure of people and the environment to engineered nanomaterials from manufactured products.

About the Report Cover and Book Design

Book layout design is by NNCO staff. Report cover design is by Kristin Roy and Shelah Morita of NNCO staff.

Copyright Information

This document is a work of the U.S. Government and is in the public domain (see 17 U.S.C. §105). Subject to the stipulations below, it may be distributed and copied with acknowledgement of NNCO. The copyrights to the portions of this report (including graphics) contributed by workshop participants and others are reserved by the original copyright holders or their assignees and are used here under the Government's license and by permission. Requests to use any images must be made to the provider identified in the image credits or to NNCO if no provider is identified.

Published in the United States of America, 2016.

Workshop Proceedings

Quantifying Exposure to Engineered Nanomaterials (QEEN) from Manufactured Products

**Addressing Environmental, Health,
and Safety Implications**

**July 7–8, 2015
Arlington, VA**

Sponsored by the

Consumer Product Safety Commission (CPSC)

in collaboration with the

National Nanotechnology Initiative (NNI)

Acknowledgements

Thanks are due to all workshop participants (see Appendix C) for sharing their experiences and insights at the *Quantifying Exposure to Engineered Nanomaterials from Manufactured Products* Workshop—the “QEEN Workshop” for short. Particular thanks are due to the plenary speakers and session co-chairs (listed on the workshop agenda, Appendix B), whose remarks are summarized in this report, to the members of the Workshop Planning Team, and to those that judged the travel and poster awards (listed below).

Workshop Planning Team

Workshop Planning Team: William K. Boyes (Environmental Protection Agency), Brendan Casey (Food and Drug Administration), Timothy Duncan (Food and Drug Administration), Cathy Fehrenbacher (Environmental Protection Agency), Charles Geraci (National Institute for Occupational Safety and Health), Elaine Cohen Hubal (Environmental Protection Agency), Debra Kaiser (National Institute of Standards and Technology), Dragan Momcilovic (Food and Drug Administration), Vladimir Murashov (National Institute for Occupational Safety and Health), Elijah Petersen (National Institute of Standards and Technology), Jeffery Steevens (U.S. Army), Treye Thomas (Consumer Product Safety Commission), and Katherine Tyner (Food and Drug Administration).

QEEN Conference Travel Awards and QEEN New Investigator Award Judges: Deborah Burgin (Agency for Toxic Substances and Disease Registry), Custodio Muianga (Agency for Toxic Substances and Disease Registry), Mary K. Schubauer-Berigan (National Institute for Occupational Safety and Health), Jeffery Steevens (U.S. Army), and Lipiin Sung (National Institute of Standards and Technology).

National Nanotechnology Coordination Office (NNCO) Contract Staff: Jewel Beamon (Events Manager), Shelah Morita (NEHI Executive Secretary and QEEN Workshop Project Manager), Diana Petreski (Financial Manager), and Kristin Roy (IT Director).

Note-Takers

Special thanks are also due to the NNCO staff members and AAAS Fellows who took notes at the workshop breakout sessions and throughout the workshop:

NNCO Contract Staff: Tarek Fadel, Geoff Holdridge, Mike Kiley, Stephen Lehrman, Shelah Morita, Marlowe Newman, and Stacey Standridge

AAAS Fellow: Quinn Spadola (NNCO)

Report Writing and Editing

The report was prepared by Shelah Morita (NNCO Contract Staff). The manuscript was edited by Pat Johnson (NNCO contract staff) and Geoff Holdridge (NNCO Contract Staff Director).

Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and workshop participants and do not necessarily reflect the views of the United States Government or the authors’ or other workshop participants’ parent institutions. Additionally, mention of trade names or commercial products does not constitute endorsement or recommendation by any of the aforementioned parties. This report is not a consensus document but rather is intended to reflect the diverse views, expertise, and deliberations of the workshop participants.

Dedication

This workshop report is dedicated to Paul J. Liroy, PhD, an internationally renowned exposure scientist who died while returning home from the QEEN Workshop. Dr. Liroy was most widely known for his work studying exposure to dust during and after the September 11, 2001, attacks on the World Trade Center. Professor and Vice Chair for the Department of Environmental and Occupational Medicine at the [Rutgers Robert Wood Johnson Medical School \(RWJMS\)](#), Dr. Liroy was a New Jersey native, born on May 27, 1947, in Passaic, NJ. He was also Deputy Director for Government Relations at the Rutgers [Environmental and Occupational Health Sciences Institute](#) and served as Director of the institute's program in exposure science. Since 2002, he has been identified by *Reuters* as one of the most cited scientists in the category of environment and ecology.

Paul Liroy was a driving force in exposure science; he served on various U.S. Environmental Protection Agency (EPA) and National Research Council (NRC) committees as a tireless champion for the field. A major focus of his research was defining the fundamental principles of human exposure science and their application to state, national, and international environmental health problems. This emphasis included research on the Toms River Cancer Cluster, chromium exposure and health effects in Jersey City, NJ, ozone and asthma, air pollution in China, and nanoparticles in consumer products. During the QEEN workshop, he expressed to his colleagues that, of all the research work he has done, he was most proud of his work in connection with exposure of first responders and others after the September 11 attacks.

Dr. Liroy was involved in exposure science at many levels. In New Jersey, he was Chair of New Jersey Clean Air Council, member of the Science Advisory Board for the NJ Department of Environmental Protection, and on the Executive Committee of the [University Center on Disaster Preparedness and Emergency Response](#) of RWJMS Hospital. Nationally, he served on the [Science Advisory Board](#) of the U.S. EPA and as the Co-Chairman of the U.S. Consumer Product Safety Commission's [Chronic Hazard Advisory Panel on Phthalates and Phthalate Alternatives](#). He was a member of the [National Academy of Sciences Board on Environmental Studies and Toxicology](#), was Chair of the NRC's first committee on exposure assessment, and was Vice Chair of the NRC Committee on Exposure Science in the 21st Century. Internationally, Dr. Liroy founded the [International Society for Exposure Science](#) and was its president from 1993–1994. He participated in the [U.S.–Canada International Joint Commission Air Quality Advisory Board](#) (1992–2007) and was a fellow of the [Collegium Ramazzini](#), Carpi, Italy.

Dr. Liroy was an editor for seven journals that deal with environmental science, human exposure, and air pollution. Most recently, he was Associate Editor of the journal *Environmental Health Perspectives* and Deputy Editor in Chief of the *Journal of Exposure Science and Environmental Epidemiology*. He published over 290 peer-reviewed papers, including reviews and vision on science and science policy and ethics. He also contributed book chapters and editorials, and published five books, including *Dust: The Inside Story of its Role in the September 11th Aftermath* and *Exposure Science*.

Preface

This report on *Quantifying Exposure to Engineered Nanomaterials (QEEN) from Manufactured Products – Addressing Environmental, Health, and Safety Implications* is the result of a technical workshop sponsored by the Consumer Product Safety Commission (CPSC) and co-hosted by the National Nanotechnology Initiative (NNI) on July 7 and 8, 2015, in Arlington, VA. The main goals for the workshop were to (1) assess progress in developing tools and methods for quantifying exposure to engineered nanomaterials (ENMs) across the product life cycle, and (2) to identify new research needed to advance nanotechnology environmental, health, and safety exposure assessment for nanotechnology-enabled products. The workshop included an overview of the field by exposure science experts as well as technical sessions highlighting current research on quantifying exposure at different stages of the product life cycle and in different product media and environments. It also included a poster session and several roundtable discussions organized to help participants better understand the challenges and accomplishments thus far in exposure science.

This report summarizes the presentations and discussions of over 200 participants from the exposure science community regarding progress during the last decade in quantifying ENM exposures. Current gaps in characterization tools and techniques are identified and discussed, along with exposure assessment methodologies, and simulation and modeling tools. Finally, the report suggests a path forward that will help bridge exposure science with toxicology and ultimately benefit data-based risk assessment and risk-based decision making for nanotechnology-enabled products.

On behalf of the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council, we thank Treye Thomas, Chuck Geraci, Elijah Petersen, and Elaine Cohen Hubal for taking the lead in organizing this workshop. Thanks are also due to the Nanotechnology Environmental and Health Implications (NEHI) Working Group of the NSET Subcommittee for leading the planning effort on behalf of NSET, and to the other members of the workshop planning team (listed on the previous page). We also thank all the speakers, session co-chairs, poster judges, and participants for their contributions to the workshop. We trust that you will find this report to be a valuable resource for the NNI, the nanotechnology environment, health, and safety (EHS) research community, and other stakeholders as we work together to promote the responsible development of nanotechnology.

Lori Henderson
Co-Chair
NSET Subcommittee

Lloyd Whitman
Co-Chair
NSET Subcommittee

Michael Meador
Director
NNCO

Table of Contents

Front Matter

Acknowledgements.....	ii
Dedication	iii
Preface	iv
Executive Summary.....	vii

Chapters

1. Introduction	1
2. Life Cycle Considerations for Quantifying Exposure.....	3
The Application of Exposure Science to the Life Cycle of Consumer Products.....	3
Occupational Exposure: Current State, Challenges, and Future Research	5
Health Risk Driven Exposure Assessment for Consumers during the Life Cycle of Nanomaterial- Containing Products	7
Ecological Exposure: Review of the State of the Science	9
Linking Life Cycle-Specific Exposures to Biological Impact of Nanomaterials.....	11
3. Exposure Quantification Studies by Receptor Population along the Product Life Cycle	13
Worker Exposure Studies	13
Consumer Exposure Studies I: General Products.....	14
Consumer Exposure Studies II: Food, Food Contact, and Personal Care Products.....	18
Ecological and General Population Exposure Studies	24
Exposure Quantification Studies by Receptor Population Roundtable.....	26
4. Measuring and Modeling Exposure in Various Media and Pathways.....	29
Measuring and Modeling Exposures to Nanomaterials in Complex Systems.....	29
Environmental Multimedia Distribution of Nanomaterials.....	35
Exposure in Biological Systems: Review of the State of the Science	39
5. Exposure Quantification Studies by Medium or Pathway	43
Exposure Studies in Gaseous Media.....	43
Exposure Studies in Aqueous Media	47
Exposure Studies in Biological Media.....	49
Epidemiology: The Exposure–Health Interface	51
Exposure Quantification Studies by Medium or Pathway Roundtable	54
6. Conclusions and Next Steps.....	56
Exposure Science in the 21 st Century: How its Principles Can Transform Safe and Sustainable Innovation and the Development of Nanomaterial Products.....	56
U.S.–EU Collaboration on Exposure: The <i>Exposure Through Product Life</i> Community of Research....	57
Common Themes and Next Steps	58
7. References.....	59

Appendices

Appendix A. Posters Presented.....	69
Appendix B. Workshop Agenda	80
Appendix C. List of Workshop Participants.....	84
Appendix D. Glossary	89
Appendix E. List of Acronyms	91
Appendix F. Tools and Methods Index	93
Appendix G. Author Index	95