

## 3. Exposure Quantification Studies by Receptor Population along the Product Life Cycle

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### Worker Exposure Studies

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The literature on worker exposure is limited but growing in size and pertinence. Initially, the focus of research was on exposures to workers handling raw, as-manufactured nanomaterials in laboratories and small production facilities. Research in Europe and the United States has more recently been focused on potential exposures to workers handling products after the nanomaterials are incorporated into matrices such as polymers, coatings, and cementitious products [56]. A major review of 54 studies on release of nanomaterials from solid nanocomposites along the life cycle from drilling and sanding to eventual shredding, incineration, and composting provided a broad foundation for this workshop session [57, 35]. There are several methods for measuring releases from nanocomposites [58]. For carbon nanotubes (CNTs) and carbon nanofibers (CNFs), new NIOSH findings from a range of workplaces add important exposure data [59]. There is an innovative thermophoretic personal sampler for collecting airborne nanoparticles on a grid for direct analysis by transmission electron microscopy [60]. The technology promises to reduce the number of overloaded filters during sampling, which has meant voided samples in the past.

Potential worker exposure during manufacture of nanotechnology-enabled products (NEPs) remains poorly understood. The overwhelming majority of peer-reviewed papers deal with hazards, not exposures. The data from 54 studies investigating release from manufactured nanocomposites containing a variety of nanomaterials (primarily CNTs, TiO<sub>2</sub>, and SiO<sub>2</sub>) were difficult to interpret and compare. There was a dearth of experimental studies; across the remaining studies, methods and materials diverged widely. The review revealed a major research need for rigorous validation of methods used to induce release from nanocomposites. Additionally, the test materials need to be commercially viable nanocomposites, not the novel, lab-made materials used in many of the studies. Given these caveats, the review showed that ultrafine particles of the matrix were released under all of the release scenarios, but only occasionally did researchers actually see nanomaterials fully dissociated from the matrix.

Currently available data suggest that when manufacturers follow good industrial practices, worker exposure to carbon-based nanomaterials can be minimized to safe exposure levels. NIOSH has set a recommended exposure level (REL) for CNTs and CNFs of 1 µg/m<sup>3</sup> as an 8-hour time-weighted average (TWA) of elemental carbon (EC) for the respirable size fraction. Recently, the NIOSH Nanotechnology Field Studies team published an industry-wide exposure assessment among U.S. CNT and CNF manufacturers and users [61]. They concluded that elemental carbon mass exposures are detectable and reliable, and

the background-corrected data showed that 96% of respirable samples were below the REL. Inhalable samples have had a higher percentage that exceeded the REL, but NIOSH does not presently have an occupational exposure level for the inhalable portion. A life cycle analysis of CNT composites [62] came to the same conclusion as the meta-analysis that, in general, individual CNTs rarely come out of the matrix material when subjected to a variety of processes that could cause release (i.e., sawing, cutting, drilling, or weatherization). The researchers did report generation of airborne clusters of CNTs not observed during saw-cutting of similar composites. Even though individual CNTs were not being released from the composites, aggressive mechanical actions were generating high exposures to nanoparticles of the matrix. Thermal degradation of the composite similarly generated ultrafine aerosols of less than 5 nanometers.

### **Common Themes from the Concurrent Session Presentations and Discussions**

Exposure controls should be initiated during synthesis and processing of CNT nanocomposites. The nanotoxicology community should focus on actual exposures along the nanomaterial life cycle, mixtures of chemistries, and exposures of nanomaterials at doses relevant to human health. Most of the worker exposure occurs when CNTs are harvested from the reactor and then processed into the nanocomposite. However, the NIOSH Field Team's experience suggests that CNTs and CNFs can migrate from the production floor throughout the facility by hand or glove contact with doors and surfaces. This transmission could indirectly expose workers to CNTs and CNFs. Because of the variety of nanomaterials and matrices, it would be good to develop several standard reference materials for the most common realistic nanocomposites and perform a standard series of tests to develop release data that can be used for comparisons. There have not been any exposure studies of nanocellulosic structures.

We are in a new paradigm about rolling out an innovative technology, and we want to do it right, including for workers, who are the first to experience exposure. Will we be able to make predictions from worker exposure data? Have we chosen the proper metrics? If so, is there an issue with the sampling and analytical technology catching up with new materials to provide better measurements? Do we know enough about the potency of materials to set a baseline or floor or even to take some nanoparticles out of consideration from a toxicological basis? The next horizon in toxicological measurements may involve simultaneously collecting materials for the toxicological studies while conducting exposure studies.

Clearly, more work is needed to relate test scenarios to real-world conditions and to establish what, if any, differences exist in the release dynamics between nanocomposites and conventional composites. Research is also needed to better characterize the relationship between released nanomaterial detection and dosage of toxicological significance.

## **Consumer Exposure Studies I: General Products**

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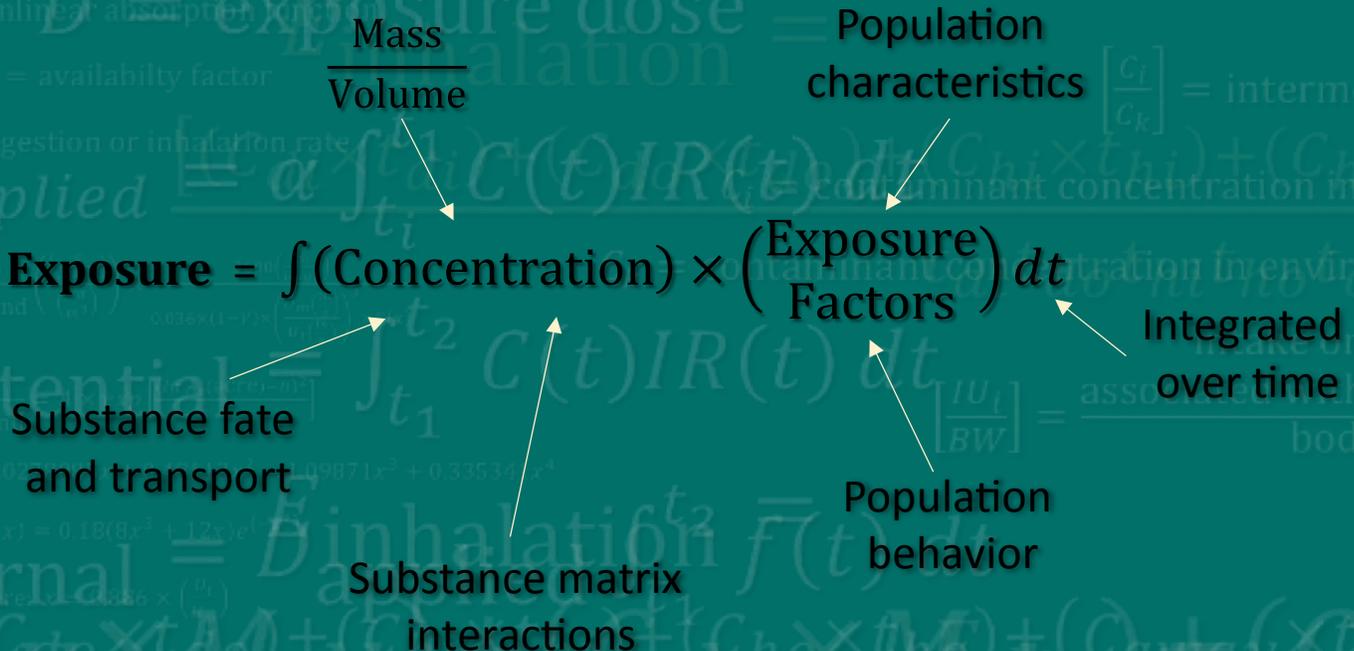
Although it is relatively straightforward to assess release from consumer products for the worst-case scenario (in which all engineered nanomaterials [ENMs] contained in the product are released) and for the best-case scenario (in which none of the ENMs are released), a realistic and environmentally relevant exposure assessment is much more challenging. This challenge arises because it requires scientists to consider the entire life cycle of products and their individual expected usage scenarios. A comprehensive

# 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**  
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**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](http://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**

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