Nanoparticle Occupational Safety and Health (NOSH) Consortium
Executive Summary

Background

The Nanoparticle Occupational Safety and Health (NOSH) Consortium was formed in December 2005 with 16 full and strategic members, including Procter & Gamble, DuPont, Dow Chemical, Intel Corporation, Air Products & Chemicals, Inc., Boeing, Degussa, Department of Energy Office of Science, Environmental Defense, GE, UK-Health and Safety Executive, Kimberly-Clark, US-NIOSH, PPG, and Rohm & Haas. The goal of the consortium was to answer specific questions which would benefit a broad global audience in terms of helping to define what would be best practice to protect workers with respect to handling engineered nanoparticles. The idea behind the formation of the consortium was to pool resources in order to improve the opportunities for success in a timely manner, to provide a wide spectrum of ideas, and to bring new perspectives to the group.

The consortium was chaired by Gordon Peters of Proctor & Gamble, with Michele Ostraat and Keith Swain of DuPont as the project co-leaders. Each member of the consortium had a seat on the project Advisory Board which met, mostly by teleconference, ten times over the course of the project. The Advisory Board's role was to define the deliverables, agree with any amendments to the project plan, and decide how best to communicate the results of the project to a broader audience.

Transparency was a primary aim of the group. Presentations were delivered at 11 scientific and health and safety conferences between 2005 and 2007. The NOSH Consortium is also in the process of submitting publications to peer reviewed journals. One paper is in final review, a second in initial review, a third is in draft form prior to submission and 4 more manuscripts are in preparation.

The main project started in January 2006 and was completed in June 2007. A short phase 2 was undertaken from July – October 2007. Results for the entire program are included in this document.

Deliverables

The Advisory Board agreed to three main deliverables:

1 a) Synthesis of aerosol nanoparticles of various chemistries, b) Characterization of aerosol instruments, c) Examination of aerosol behavior as a function of time;
2 Development of a portable aerosol monitor, and
3 Development of a test method to measure filtration efficiency and measurement of nanoparticle filtration efficiencies of commercially available filter media.

Deliverable Results Summary:

1a) Synthesis methods for stable sources of aerosol nanoparticles of SiO_2, citric acid, silver, and polystyrene latex (PSL) have been developed for controlled particle synthesis d_p < 100 nm The SiO_2 aerosol nanoparticle synthesis has been shown to be sufficiently stable over long time periods (6 months) and may have applications in an aerosol nanoparticle standard method. As a NIST traceable standard, the 100 nm PSL has been successfully used to calibrate aerosol instruments. The SiO_2 and citric acid synthesis methods are used on a continual basis in other areas in the program, including portable monitor development, aerosol chamber, and filtration studies. Assessment of nanosized aerosol generation from a bulk sample of montmorillonite clay was completed. Although the findings are preliminary, they illustrate the potential for bulk materials to generate nanosized aerosols in situations such as bag filling or from spillage. From an exposure control perspective, these results reinforce the need for careful risk assessment of each step of operations involving nanomaterials. Methodologies to measure the particle size and number concentration of aerosolized particles generated from mechanical processing of engineered nanomaterials filled polymer films under various experimental conditions have been demonstrated. Additional work is required to

1b) Aerosol instrument characterization has been successfully completed for numerous aerosol instruments, including the long-and nano-differential mobility analyzers, electrostatic-based impactor (ELPI), aerosol chargers and neutralizers, and optical (CNC) and electrostatic (AE) detectors. These instruments continue to be used in all other deliverables of the program.

1c) Aerosol chambers have been used to understand aerosol behavior over time. Significant observations include evidence that aerosol nanoparticles d_p > 40 nm may not behave as gases as they do not appear to diffuse readily into the entire aerosol chamber volume. Thus, particles d_p > 40 nm may be more readily contained in gas flows and directed to suitable air handling or filtration units than originally perceived. Particles d_p < 20 nm appear to suffer losses ~ 50% (through agglomeration with other aerosol particles) such that they grow to particle sizes d_p > 100 nm, a size range in which current occupational health systems have shown to be effective in particle removal. External forces further increase the particle loss through the aerosol chamber with the smallest particles d_p < 20 nm experiencing the highest particle losses. With experiments involving relative humidity in the range 0 - 40%, negligible effect on aerosol concentration or particle size distribution as a function of time was observed. Furthermore, adding typical ambient levels of larger aerosol particles had little or no effect on particle size distribution or number concentration as a function of time under conditions tested. However, even gentle air mixing within the aerosol chamber had a marked effect in the aerosol chamber, resulting in a decreased aerosol nanoparticle number concentration and a shift in the size distribution to larger particle sizes.

2) The needs of a portable aerosol monitor were identified by the broad NOSH membership and have been communicated to interested parties, including external instrument developers, though individual discussions as well as through an instrument vendor workshop. The main requirements related to reasonable price, ease of use and size. Two Non Disclosure Agreements with DuPont have been established.

3) Test methods to measure filtration efficiency of commercially available filter media to aerosol nanoparticle exposure have been developed. The versatile test method is able to distinguish filtration efficiencies as a function of particle size and of exposure time. Additional variables studied include particle chemistry, particle charge, and extended time testing.

a) N95, N100, and P100 filter media in general perform within their specified filtration efficiency to aerosol nanoparticles d_p <100 nm. b) In most cases, these filter media demonstrate significant filtration efficiency to SiO_2 and citric acid aerosol nanoparticles.

c) Differences in filtration efficiency (initial and as a function of time) are observed for filter media upon exposure to charged (filtration efficiency decreases with time) and uncharged (filtration efficiency increases with time) particles.

d) Differences in filtration efficiency are observed between SiO_2, TiO_2, NaCl, and citric acid aerosols, with NaCl and citric acid demonstrating slightly enhanced filtration efficiency compared with SiO_2 and TiO_2.

e) Prolonged usage beyond manufacturers recommended lifetimes of filter media may reduce the filtration efficiency, particularly if stored overnight.

Occupational Safety and Health Implications of the Results:

Deliverable 1: Nanoparticle Behavior as a Function of Time

a. Aerosol particles $d_p > 40$ nm may not behave as gases and do not appear to diffuse readily into available volumes.

b. Smaller aerosol particles $d_p < 20$ nm can be made to aggregate by placing obstructions in the aerosol path. This aggregation causes a decrease in the concentration of smaller particles and an increase in the concentration of larger particles.

c. Increasing the residence time/internal volumes that aerosol particles occupy appears to reduce the number concentration of aerosol particles that pass through that volume.

d. Air movements appear to enhance particles loss for particles $d_p < 60$ nm either due to losses to fixed surfaces or to collisions with other particles to form particles $d_p > 100$ nm.

e. Materials of construction may enhance particle losses slightly, with Lucite® demonstrating higher particle losses versus aluminium. Charged and uncharged aerosol particle losses also depend upon placement and types of valves, dimensions and placements of bends and turns, and length of tubing and types of connections.

Deliverable 3: Filter Media Efficiency

a. Filter media from different manufacturers differ with respect to filtration efficiency.

b. N100 filter media has higher % filtration efficiency for aerosol nanoparticle removal than N95 filter media.

c. Charged and uncharged aerosol particles have different filtration efficiencies through filter media tested.

d. Charged aerosol particles have higher filtration efficiencies. Charged particle filtration efficiency generally decreases with time. Prolonged usage beyond manufacturer recommended lifetimes of filter media may reduce the filtration efficiency, particularly if stored overnight.

e. For N100 and P100 filter media tested, the filtration efficiency was $\geq$ 99.97% upon exposure to different particle chemistries. Particle chemistry does appear to play a role in filtration with NaCl and citric acid particles captured 10-100X better than SiO_2 or TiO_2.

f. For N100 and P100 filter media tested, the filtration efficiency was $\geq$ 99.97% for the different % RH tested. Increasing relative humidity appears to enhance particle capture in the range 0-20% RH.

Summary

Nanotechnology is a rapidly emerging and enabling technology that has the potential for significant advances in many different fields. Safety and health professionals acknowledge the current unknown risks associated with nanoscale materials and the need for safe handling of nanoscale materials guidance. This project work sponsored by the NOSH Consortium and the results achieved by the project team are presented to provide knowledge for those that are engaged in risk management for engineered nanomaterials. This work has made a major contribution towards addressing knowledge gaps, raising awareness and understanding of workplace containment and control measures, and setting the stage for further work in this arena.

Recommendations for Future Work

Throughout the NOSH Consortium, several recurring opportunities for future work have been identified, often through discussions at conferences and from Advisory Board Member professional networks and contacts. These areas are divided into two categories: Research Areas and Strategic Directions

Research Areas

1 Nanomaterial Inhalation Toxicology
2 Explosion Hazard Testing of Nanomaterials
3 Carbon Nanotube Materials

Strategic Direction and Needs Prioritization

1 Prioritization of Federally Funded Research Projects
2 International Collaborations on Occupational and Environmental Health

Research Areas:

1. Nanomaterial Inhalation Toxicology

a. Potential collaborations with the National Institute of Environmental Health Sciences (NIEHS), the National Institute of Biomedical Imaging and Bioengineering (NIBIB), and the Foundation for NIH to discuss development of the NanoHealth Enterprise.

Systematically investigate the fundamental interactions of engineered nanomaterials with biological systems.

Identify areas of mutual scientific interest and potential components of a NanoHealth Enterprise—a partnership of NIH institutes, other federal agencies, industry, stakeholders, and foundations to pursue the very best science and leverage investment for research efficiencies.

Address questions critical to the development of biocompatible nanoscale materials, such as the role of elemental composition, size, shape, and surface chemistry in biological response.

b. Battelle and Pacific Northwest National Laboratory have communicated a high level of interest in conducting inhalation toxicology testing of nanomaterials in collaboration with a Consortium. They have existing facilities and expertise in which to conduct this program.

2. Explosion Hazard Testing of Nanomaterials

Battelle and Pacific Northwest National Laboratory have communicated a high level of interest in conducting explosion and dust hazard testing of nanomaterials in collaboration with a Consortium. They have existing facilities and expertise in which to conduct this program.

3. Carbon Nanotube Materials

The inclusion of carbon nanotube materials in occupational safety and health studies remains a high priority for many organizations. Currently, the EU NANOSAFE2 program is including carbon nanotube materials as one of many nanoscale materials for testing.

Strategic Direction and Needs Prioritization:

4. Prioritization of Federally Funded Research Projects

Identification of priorities and needs to guide priorities for US and EU federally funded research programs.

- Collaboration with NIOSH and other government agencies on occupational safety and health priorities. These collaborations can include a variety of activities, including, for example:
  a) Participation in NIOSH field team visits and discussion of results and findings to a broader audience.
  b) Submission of existing documents and industrial procedures in databases of best work practices. c) Submission of documentation to the NIOSH Nanoparticle Information Library.
  d) Providing feedback to funding agencies on how safety protocols and academic research are being applied in industry, including if the tools and knowledge are being used, then how and if they are not being used, then why.
  e) Providing the industry voice to guide priorities and project scope for new knowledge generation, including applied needs such as desired measurement capabilities and defined instrument specifications.
- Interactions with NanoHealth Enteprise on interactions of engineered nanomaterials with biological systems, specifically including the definition and development of program needs and scope in order to propose program funding opportunities.

5. International Collaborations on Occupational and Environmental Health

Share methods and findings with international communities that are also studying occupational and environmental health efforts, including EU NANOSAFE2, active participation in current and future consortia and collaborations focused on nanotechnology and occupational and environmental safety and health, and support and participation in international forums on occupational and environmental health.

<u>Presentations and Participation:</u>

2nd International Symposium on Nanotechnology, Occupational and Environmental

Health 2005
AAAR Annual Meeting, 2006
International Aerosol Conference, 2006
American Institute of Physics, Industrial Physics Forum, 2006
AIChE, Health Effects of Nanoparticles, 2006
International Conference on nanotechnology Occupational and Environmental Health and Safety, 2006
Industrial Technologies Program (ITP) Workshop for DOE on "Energy Efficiency of Nanomanufacturing," 2007
President's Council of Advisors on Science and Technology (PCAST), 2007
3^{rd} International Symposium on Nanotechnology, Occupational and Environmental Health, 2007
NNI/NIST Workshop "Standards for Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials," 2007
Nanotechnology Collaborations: Nanoparticle Occupational Safety and Health Consortium, University of California Santa Barbara Center for Nanotechnology in Society, 2007

Publications (final review, *Journal of Environmental and Occupational Health*):

- SiO_2 Aerosol Nanoparticle Reactor for Occupational Safety and Health Studies

Publications (initial review):

- Versatile Aerosol Nanoparticle Reactor and Filter Housing Characterization Capability for Occupational Safety and Health Studies

Publications (draft):

- Filter Media Filtration Results on Charged and Uncharged SiO_2 Aerosol Nanoparticles with d_{50} ~ 10, 30, and 60 nm

Publications (proposed):

Influence of Particle Chemistry on Measured Filtration Efficiency: Chemistry versus Relative Humidity

Aerosol Chamber Studies Investigating Aerosol Behavior as a Function of Time; Chamber Volume, Materials of Construction, Particle Charge

December 13, 2007