Effectiveness of Personal Protective Equipment (PPE) against Nanomaterials

Pengfei Gao, Ph.D., CIH

National Institute for Occupational Safety and Health
National Personal Protective Technology Laboratory
Pittsburgh, PA 15236
Email: PGao@cdc.gov
Phone: 412-386-6885

PPE Used in Carbonaceous Nanomaterial Industry

- **Every company surveyed reported using some form of PPE to minimize worker exposure**
- **Dermal exposure reduction (Protective clothing)**
  - Gloves (97%) were most common, followed by aprons (47%) and Tyvek suits (43%)
- **Inhalation exposure reduction (Respiratory protection)**
  - 77% of organizations reported using respiratory protection
  - Half-facepiece air purifying respirator with either N/P-100 cartridge most common (43%) followed by N95/P100 filtering half-facepiece respirator (20%)

Dahm, M. M., M. S. Yencken, et al. (2011). "Exposure Control Strategies in the Carbonaceous Nanomaterial Industry." Journal of Occupational and Environmental Medicine 53(6): S68-S73.

Importance of Understanding the Effectiveness of PPE

- **Industrial hygienists have decades of experience in controlling larger particles**
- **Key questions:**
  - Do nanoparticles behave any differently than larger particles?
  - Do new PPE selection methods need to be developed?

Effectiveness of PPE for Workers Handling Unbound Nanomaterials

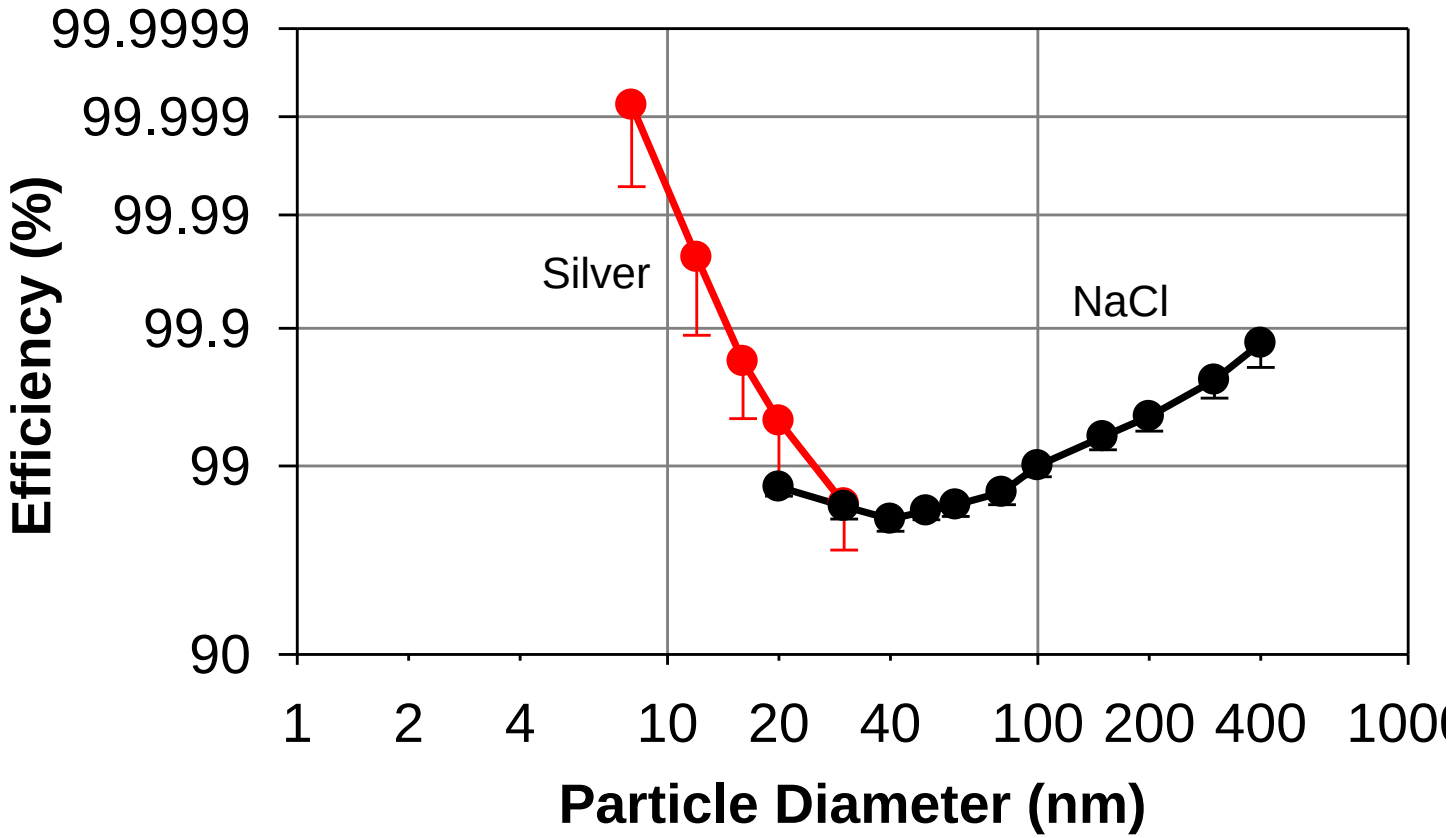
- **Effectiveness of PPE against particulates is primarily a function of leakage around the sealing areas and direct penetration though the media**
- **NIOSH research projects have addressed some of these issues**

Photo obtained from Health hazard evaluation report: HETA-2005-0291-3025, Methner-MM; Birch-ME; Evans-D; Hoover-MD

Current Recommendations

- **NIOSH research suggests that traditional respirator selection tools used for fine and ultrafine particles also apply to nanoparticles**
- **The 2004 NIOSH *Respirator Selection Logic* provides guidance for selecting an appropriate respirator**
  - e.g., a properly fit-tested, half-facepiece particulate respirator or a filtering-facepiece respirator will provide protection at exposure concentrations up to 10 times the recommended exposure level (REL). Other classes of respirators exist that provide a higher level of protection
- **Follow all of the elements outlined in the OSHA Respiratory Protection Standard (29 CFR 1910.134)**

Filtration Performance of a Typical N95 FFR



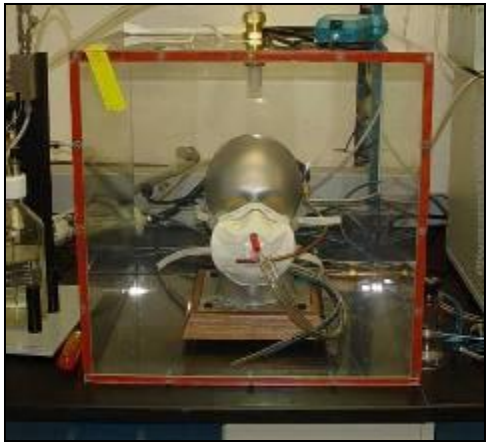
n = 5; error bars represent standard deviations Sodium Chloride (TSI 3160); Silver (custom-built) Flow rate 85 L/min

Filtration performance of NIOSH-approved N95 and P100 filtering facepiece respirators against nanoparticles, [2008] S. Rengasamy, WP King, B. Eimer and R. Shaffer, Journal of Occupational and Environmental Hygiene, 5: 556-564.

Respirator Fit

- **TSI Portacount with N95 Companion measures fit using ~40-60 nm particles**
  - Rengasamy et al. [2012] Evaluation of the Performance of the N95-Companion: Effects of Filter Penetration and Comparison with Other Aerosol Instruments, JOEH 9:7, 417-426.

- **Leak size was the largest factor affecting the number of 5 – 400 nm particles inside the facepiece of respirators worn in manikin tests**
  - Rengasamy et al. [2011] Total inward leakage of nanoparticles through filtering facepiece respirators. Ann Occup Hyg; 55: 253–63.

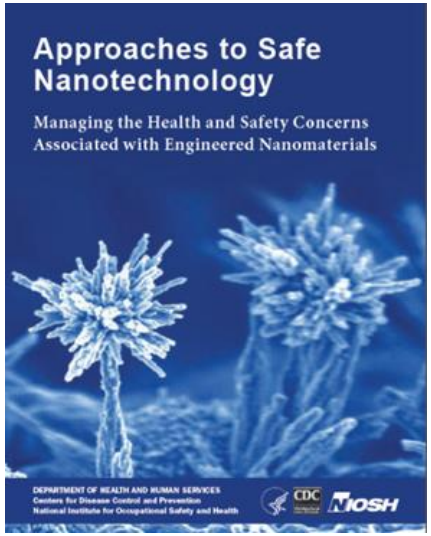


What We Have Learned?

- As predicted by single fiber filtration theory, 4 to 20 nanometer particles were captured very efficiently by respirator filter media
- The most penetrating particle size (MPPS) range for electret filter media was between 30 and 100 nanometers
- Leak size was the largest factor affecting the number of nanoparticles inside the facepiece of the respirator worn in manikin tests

Protective Clothing

- For PC&E, there is nothing equivalent to the NIOSH respirator selection logic
- There are no generally acceptable guidelines available for the selection of protective clothing against nanomaterials. Therefore, current industrial hygiene best practices should be followed



- Little data on PC&E protection against nanoparticles (aerosolized or colloidal) are available, but recent efforts by NIOSH and others are starting to fill knowledge gaps

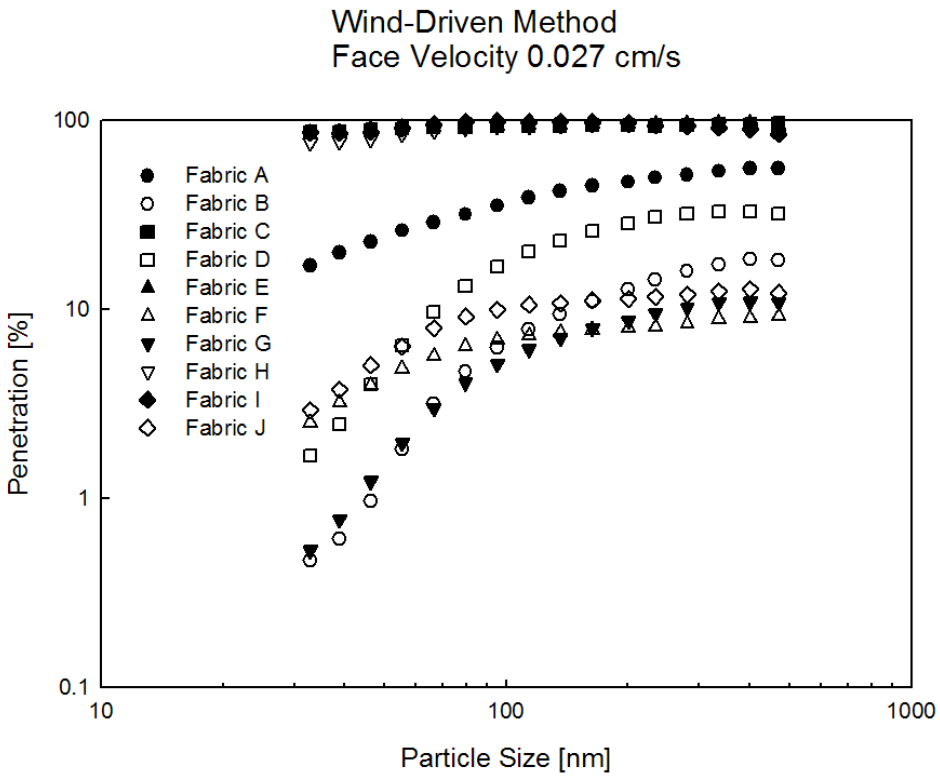
NIOSH Suggestions on Protective Clothing against Carbon Nanotubes & Nanofibers

- **Wear protective clothing and gloves when**
  - **elimination or engineering control is not successful, or**
  - **in emergency situations**
- **Double gloving may be needed when the worker requires physical protection as well**
- **Take into account the resistance of the glove to both the nanomaterial and the liquid, if suspended in liquids**
- **Use light-colored gloves and lab coats to facilitate observation of contamination by dark carbon nanotubes (CNTs) and nanofibers (CNFs)**

NIOSH Current Intelligence Bulletin -- Occupational Exposure to Carbon Nanotubes and Nanofibers. NIOSH, November 2010 Draft.

Wind-driven Particle Penetration Through Fabrics

- In general, nonwoven fabrics behave like filters
- Particle penetration increase with
  - increasing wind speed
  - increasing particle size up to 300 – 500 nm
- Particle penetration is driven by several factors of the fabrics, including:
  - air permeability
  - fiber diameter, and
  - pore size
- Protective clothing materials should not be tested like respirators



Gao, P., P. A. Jaques, T.H. Hsiao, A. Shepherd, B. Eimer, M. Yang, A. Miller, B. Gupta, and R. Shaffer: Evaluation of nano- and sub-micron particle penetration through ten nonwoven fabrics using a wind-driven approach. *J. Occup. Environ. Hyg.* 8(1):13-22 (2011).

Key Findings of Some Recently Published Papers

Citation	PPE Types	Summary of Key Findings
Golanski et al. Experimental evaluation of individual protection devices against different types of nanoaerosols: graphite, TiO_2, and Pt. J. Nanoparticle Res., (2010) 12(1): 83-89.	Tyvek, cotton and polyester clean room suits, nitrile, latex, and neoprene gloves	Air-tight fabrics made of non-woven textile seem much more efficient in protection against dry nanoparticles than cotton and polypropylene. Gloves are very efficient for dry nanoparticles.
Dolez et al.: Development of a test method for protective gloves against nanoparticles in conditions simulating occupational use. J. Phys.Conf. Ser. 304 012066 (2011).	Neoprene, butyl rubber gloves	TiO_2 (power and colloidal solutions) can penetrate through mechanically degraded gloves
Park et al.: Efficiency of protective dermal equipment against silver nanoparticles with water aerosol, J. Nanoparticle Res., 13: 3043-3049 (2011).	Polyester cleanroom wear, cotton lab coat, latex & nitrile gloves	Penetration through protective clothing was found, but not for gloves

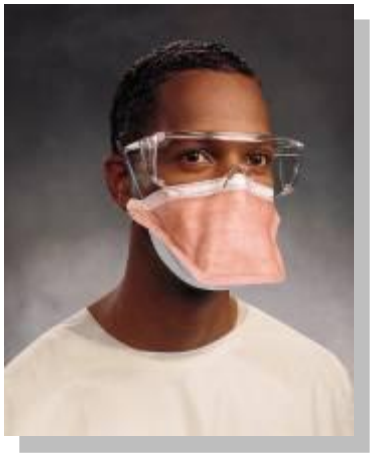
Where do we go from here?

- **PPE workplace (field) protection studies of nanotechnology workers**
- **Laboratory performance of filter media against carbon nanotubes and/or other key nanoparticle classes**
- **Gloves against engineered nanomaterials (ENMs) to address some important questions, such as:**
  - gloves resist the same to CNTs and metal oxides?
  - gloves resist the same to dry powders and liquid suspensions?
  - single gloving vs. double gloving?

Acknowledgements

- NIOSH Nanotechnology Research Center (NTRC)
- Respiratory Protection Team: Ziqing Zhuang (PI), Samy Rengasamy, Ben Eimer, Bill King, Terri Pearce, Evanly Vo, and collaborators
- Protective Clothing Team: Angie Shepherd, Zhong-Min Wang, Peter Jaques, Ta-Chih Hsiao, Tony Rozzi, and collaborators

Quality Partnerships Enhance Worker Safety & Health



Visit Us at: http://www.cdc.gov/niosh/npptl/default.html

Disclaimer:

The findings and conclusions in this presentation have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

Thank you