Effectiveness of PPE and Engineering Controls

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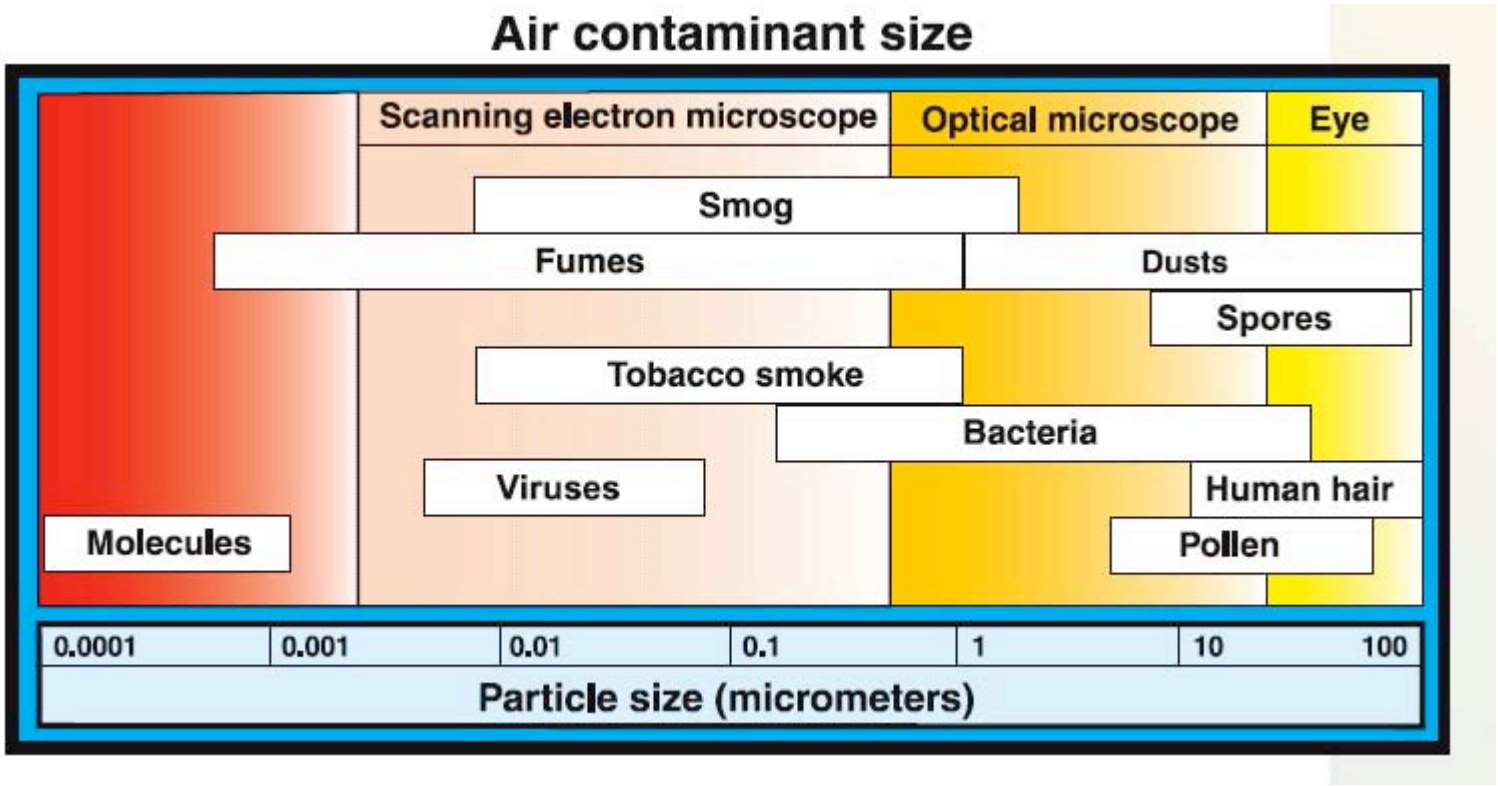
July 8th, 2008

Overview

- **Components of a Nanomaterial Risk Management Program**
- **Control Technologies in Use Today**
- **Efficacy of Selected Control Technologies**
  - Lessons Learned from the NIOSH Field Research Team
  - Filtration
  - Personal Protective Equipment (PPE)
    - Respiratory Protection
    - Dermal Protection
- **Future Research**
- **Conclusions**

What are Nanoparticles?

Nanoparticles are particles smaller than 100 nm (0.1 µm) in diameter



Adapted from: Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks, DHHS (NIOSH) Publication No. 2003-136.

Components of a Nanomaterial Risk Management Program

- **Hazard Determination**
- **Process Review**
- **Exposure Evaluation**
- **Risk Characterization**
- **Controls**

Hierarchy of Controls

Elimination/Substitution

Engineering Controls

Administrative Controls

PPE

Adapted from Figure 1, Schulte et al, Occupational Risk Management of Engineered Nanoparticles, Journal of Occupational and Environmental Hygiene, 5:4, 239-249 (2008).

Control Technologies Used in Nanomaterial Workplaces

- **ICON Survey of Current Practices in the Nanotechnology Workplace**
  - 70% of respondents reported either implementing a nano-specific EHS program or providing formal training on the safe handling of nanomaterials
  - No data reported on prevalence of elimination/substitution and administrative controls
  - All organizations reported using some form of engineering controls
  - 82% reported nano-specific PPE recommendations

Conti et al, Health and Safety Practices in the Nanomaterials Workplace: Results from an International Survey, Environmental Science and Technology, in press.

Most Common Types of Engineering Controls

- **Fume Hood**
- **Glove Box**
- **Clean Room**
- **HVAC**
- **Closed Piping System**
- **Laminar Flow Bench**
- **Bio-safety cabinet**
- **Glove bag**

Conti et al, Health and Safety Practices in the Nanomaterials Workplace: Results from an International Survey, Environmental Science and Technology, in press.

PPE Used in Nanomaterial Workplaces

- **Dermal exposure reduction (Protective clothing)**
  - Lab coats, “building suit” (whole body) most common
  - Clothing and glove selection often based upon conventional chemical hygiene criteria
- **Inhalation exposure reduction (Respiratory protection)**
  - 63% of organizations reported using some kind of respiratory protection: respirators, disposable respirators, dust masks
  - P100 (HEPA-equivalent) most commonly reported respirator specification

Conti et al, Health and Safety Practices in the Nanomaterials Workplace: Results from an International Survey, Environmental Science and Technology, in press.

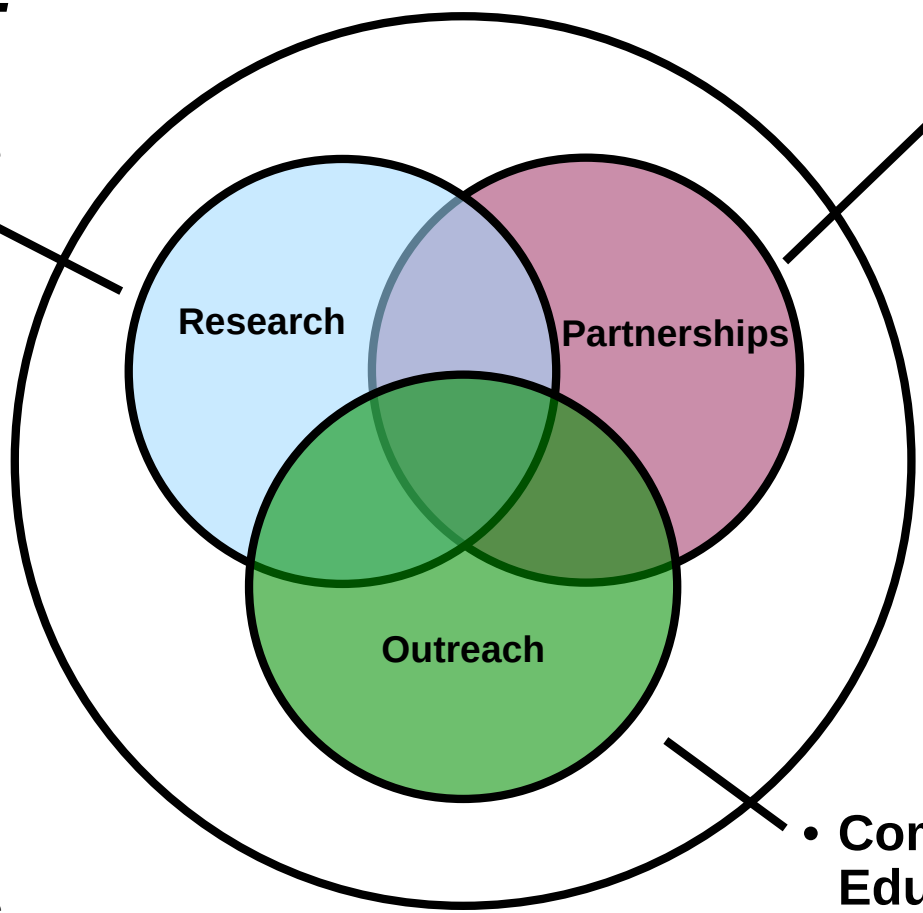
Importance of Understanding the Effectiveness of Control Technologies

- **Industrial hygienists have decades of experience controlling larger particles**
- **Key question: do nanoparticles behave any differently than larger particles?**
- **What are the limits of engineering controls and PPE with respect to engineered nanoparticles?**
- **Understanding these limits are critical for risk management**

NIOSH Nanotechnology Research

10 Critical Areas:

- **Toxicity**
- **Exposure and Dose**
- **Risk Assessment**
- **Measurement Methods**
- **Controls**
- **Safety**
- **Epidemiology and Surveillance**
- **Application**



Partners:

Government
Academia
Industry
Labor
International

- **Communication and Education**
- **Recommendations**

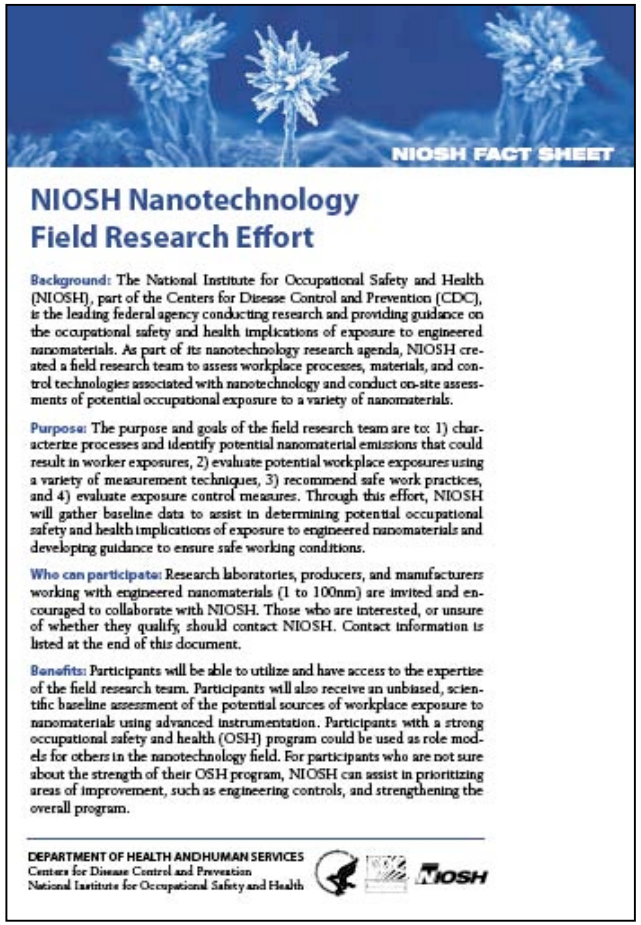
Adapted from Figure 2, Page 6 of "Progress Toward Safe Nanotechnology in the Workplace: A Report from the NIOSH Nanotechnology Research Center, DHHS (NIOSH) Publication No. 2007-123

NIOSH Nanotechnology Research: Engineering Controls & PPE

- **Engineering Controls**
  - Observations from the NIOSH Field Team
  - Filtration of nanoparticles
- **PPE**
  - Respiratory protection
  - Protective clothing

Observations from the Field Survey Team

- **Basic particle counting and sizing instruments can be used to identify emissions from nanomaterial processes**
- **Careful interpretation of the particle data is needed to differentiate between incidental (background) and process-related nanoparticles**
- ***Engineering controls do minimize workplace exposure to engineered nanoparticles***



NIOSH FACT SHEET

NIOSH Nanotechnology Field Research Effort

Background: The National Institute for Occupational Safety and Health (NIOSH), part of the Centers for Disease Control and Prevention (CDC), is the leading federal agency conducting research and providing guidance on the occupational safety and health implications of exposure to engineered nanomaterials. As part of its nanotechnology research agenda, NIOSH created a field research team to assess workplace processes, materials, and control technologies associated with nanotechnology and conduct on-site assessments of potential occupational exposure to a variety of nanomaterials.

Purpose: The purpose and goals of the field research team are to: 1) characterize processes and identify potential nanomaterial emissions that could result in worker exposures, 2) evaluate potential workplace exposures using a variety of measurement techniques, 3) recommend safe work practices, and 4) evaluate exposure control measures. Through this effort, NIOSH will gather baseline data to assist in determining potential occupational safety and health implications of exposure to engineered nanomaterials and developing guidance to ensure safe working conditions.

Who can participate: Research laboratories, producers, and manufacturers working with engineered nanomaterials (1 to 100nm) are invited and encouraged to collaborate with NIOSH. Those who are interested, or unsure of whether they qualify, should contact NIOSH. Contact information is listed at the end of this document.

Benefits: Participants will be able to utilize and have access to the expertise of the field research team. Participants will also receive an unbiased, scientific baseline assessment of the potential sources of workplace exposure to nanomaterials using advanced instrumentation. Participants with a strong occupational safety and health (OSH) program could be used as role models for others in the nanotechnology field. For participants who are not sure about the strength of their OSH program, NIOSH can assist in prioritizing areas of improvement, such as engineering controls, and strengthening the overall program.

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http://www.cdc.gov/niosh/docs/2008-121/pdfs/2008-121.pdf

An Example from the Field

- **Average percent reduction from the use of a local exhaust ventilation unit was 96 +/- 6% based on particle counts and 88 +/- 12% based on mass**

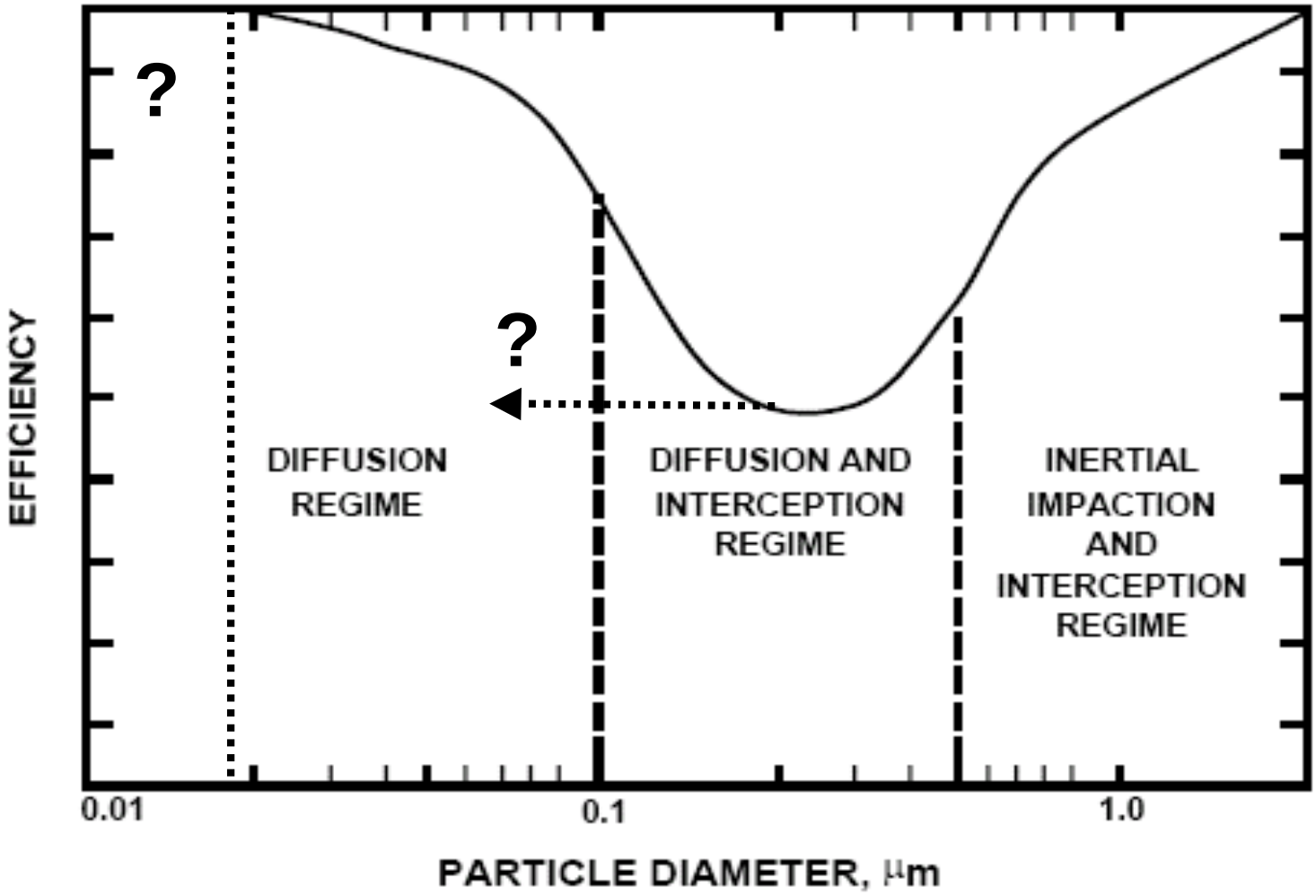
portable fume hood extractor

During reactor cleanout activities

Effectiveness of Local Exhaust Ventilation (LEV) in Controlling Engineered Nanomaterial Emissions During Reactor Cleanout Operation, M, Methner, Journal of Occupational and Environmental Hygiene, Vol. 5, June 2008, pages D63 - D69.

Data and photos courtesy of Dr. Mark Methner, NIOSH Field Research Team.

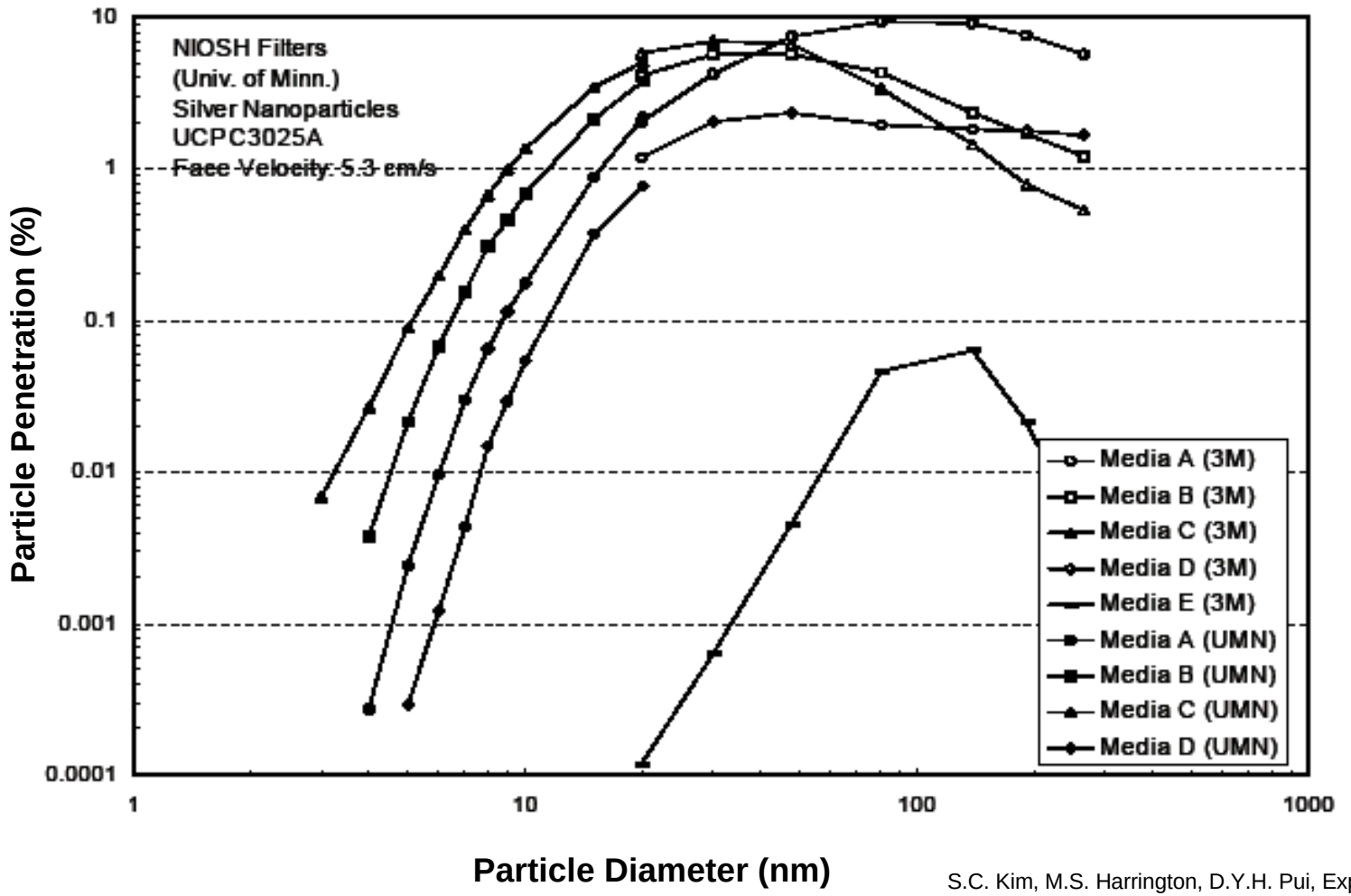
Filtration Theory



Nanoparticle Filtration Study

- **2005 - NIOSH funds Center for Filtration Research at the University of Minnesota to study nanoparticle filtration**
- **Hollingsworth & Vose fiberglass filter media**
- **Specialized filter media**
  - Media A - Corona charged blown fiber
  - Media B - Highly charged blown fiber
  - Media C - Split film fiber
  - Media D - Highly charged blown fiber
  - Media E - GORE membrane filter

No Evidence for Thermal Rebound



S.C. Kim, M.S. Harrington, D.Y.H. Pui, Experimental Study of Nanoparticles Penetration Through Commercial Filter Media, Journal of Nanoparticle Research, 9, 117-125 (2007).

Effectiveness of PPE for Workers Handling Unbound Nanomaterials

- **Effectiveness of personal protective equipment (PPE) against particulates is primarily a function of leakage around the sealing areas and direct penetration though the PPE**
- **NIOSH research projects are being conducted to address some of these issues**

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

NIOSH - 42 CFR, Part 84 Air Purifying Particulate Respirator (APR) Certification

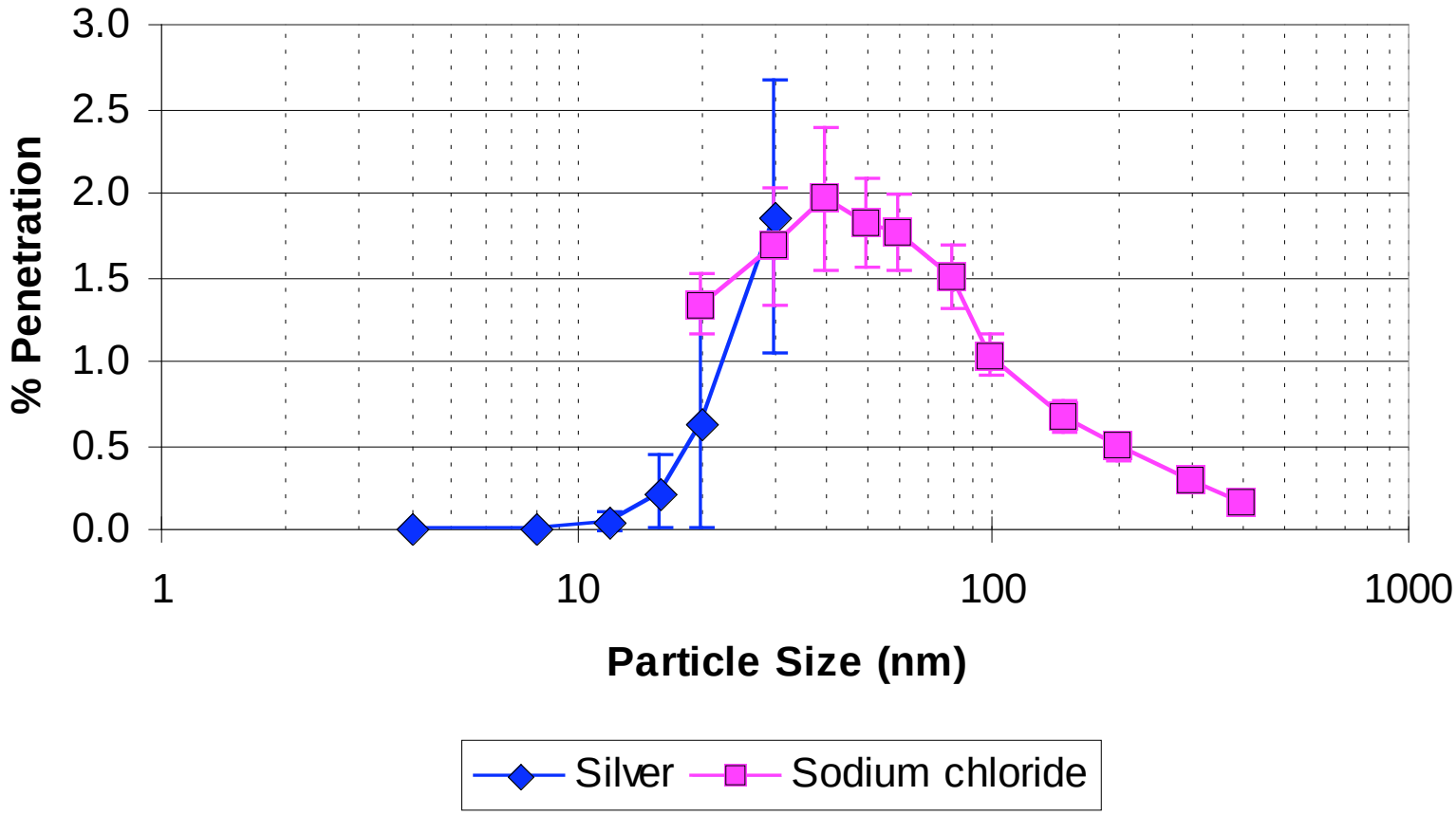
Minimum Efficiency	NaCl Test	DOP oil Test	DOP oil Test
95%	N95	R95	P95
99%	N99	R99	P99
99.97%	N100	R100	P100

- N - not resistant to oil mist
- R - resistant to oil mist
- P - protective against oil mist
- 95, 99, 100 - <u>minimum</u> filter efficiency using certification test conditions

Respirator Fit

- **No specific data available to determine if nanoparticle face seal leakage is different**
- **However, WPF studies have validated effectiveness of current methods used to fit respirators for use against gases and vapors.**
- **TSI Portacount with N95 Companion measures ~40 nm particles**
- **NIOSH is conducting controlled laboratory studies using manikins to measure face seal leakage of 5 – 400 nm particles**

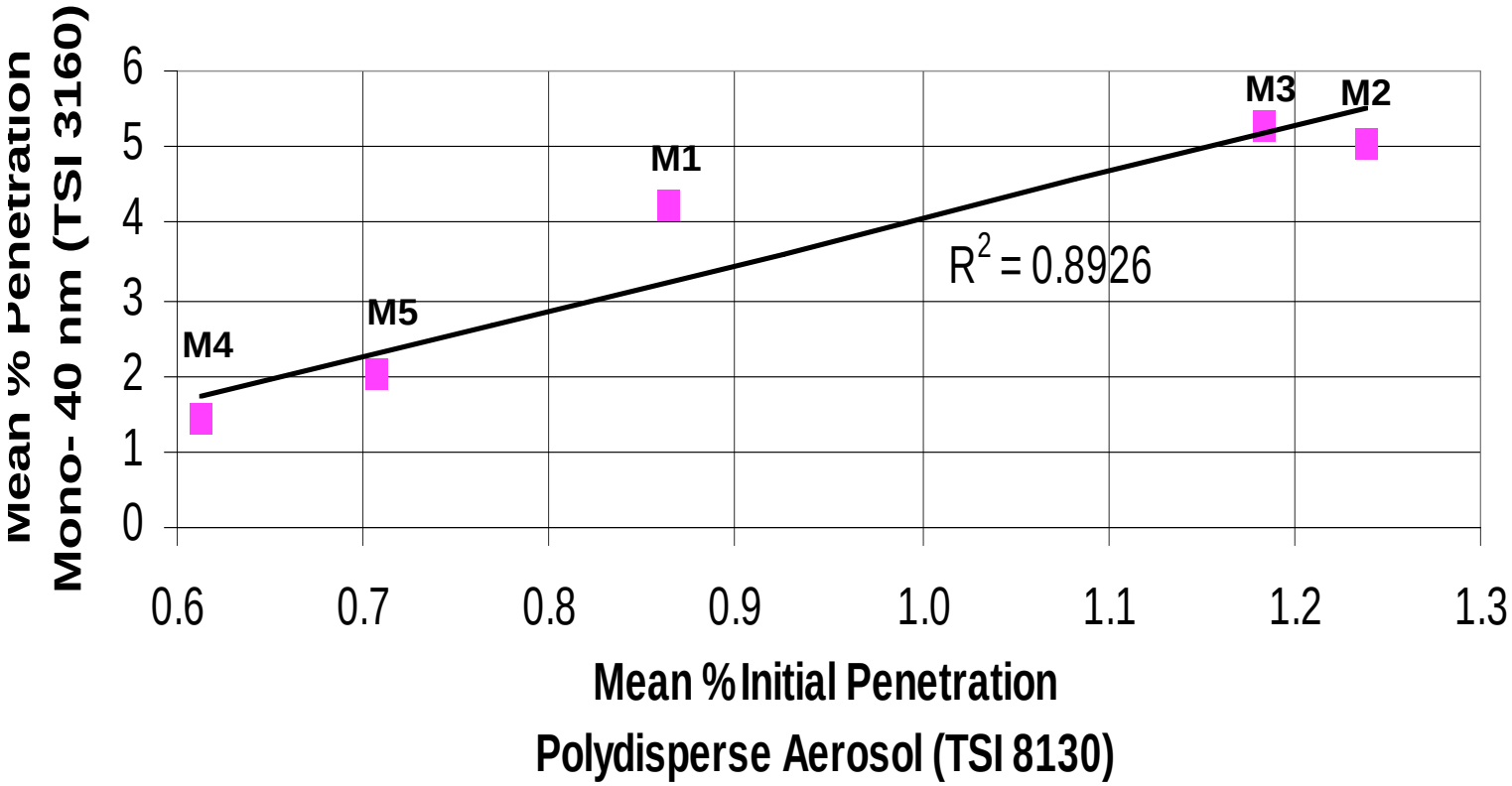
Filtration Performance of a Typical NIOSH Approved N95 Filtering Facepiece Respirator



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, S. Rengasamy, WP King, B. Eimer and R. Shaffer, Journal of Occupational and Environmental Hygiene, In Press.

Correlation of Poly- and 40 nm Monodisperse Aerosol Penetrations



Rengasamy S, Verbofsky R, King WP and Shaffer R [2007]. Nanoparticle penetration through NIOSH-approved N95 filtering facepiece respirators. Journal of International Society for Respiratory Protection, 24:49-59.

Performance of Dust Masks – Not NIOSH Certified

Category	Model #	Average % Penetration at 85 L / min		Unit Price ($)
		TSI 8130 (polydisperse)	TSI 3160 (monodisperse MPPS *)	
Low	A	1.0	4.3	0.65
Medium	B	12.1	24.2	0.33
	C	8.9	14.7	0.65
High	D	82.9	96.9	0.49
	E	82.3	87.5	0.51
	F	74.5	87.1	0.99

*MPPS for A-C ~40 nm, D-F ~300 nm

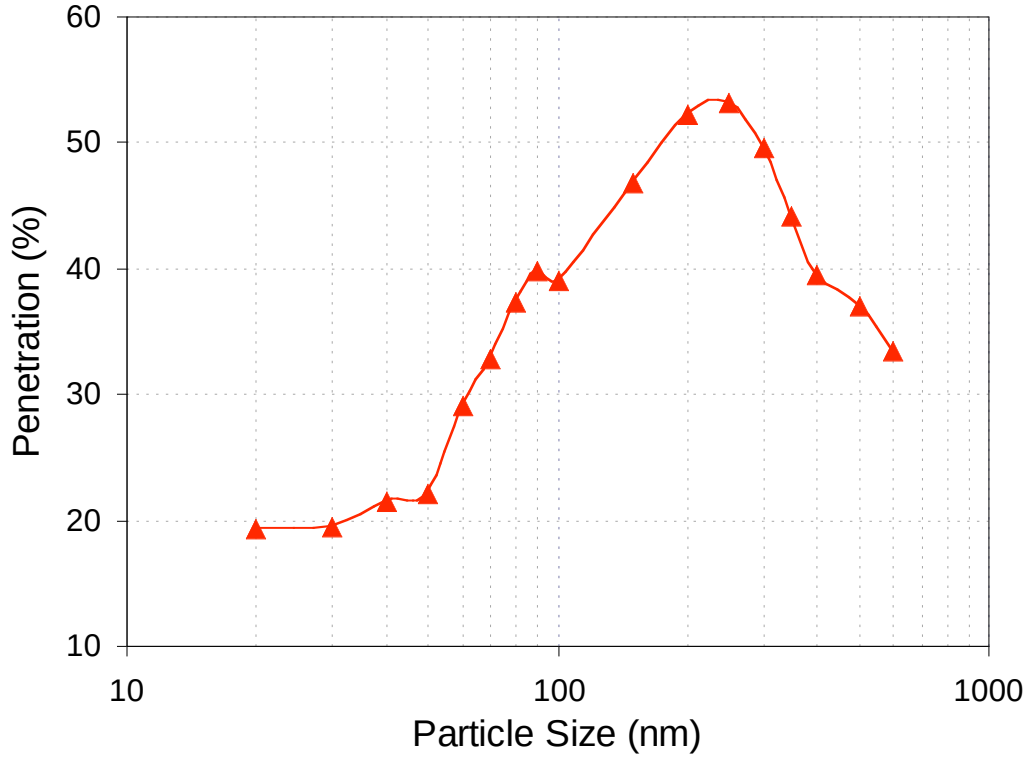
"Nanoparticle filtration performance of commercially available dust masks", Samy Rengasamy, Ben Eimer, and Ron Shaffer (in review).

Protective Clothing & Ensembles

- **No guidelines available for proper selection, use, care, and maintenance of protective clothing & ensembles (PC&E) for protection against exposure to nanoparticles**
- **Some data on protection provided by PC&E against particulate hazards exist for military, clean-room, and asbestos remediation garments**
- **Data on the relative contribution of leakage around seams/closures vs. direct particle penetration is lacking**
- **NIOSH immediate focus is on assessing direct penetration through fabric swatches**

Particle Penetration Through Clothing

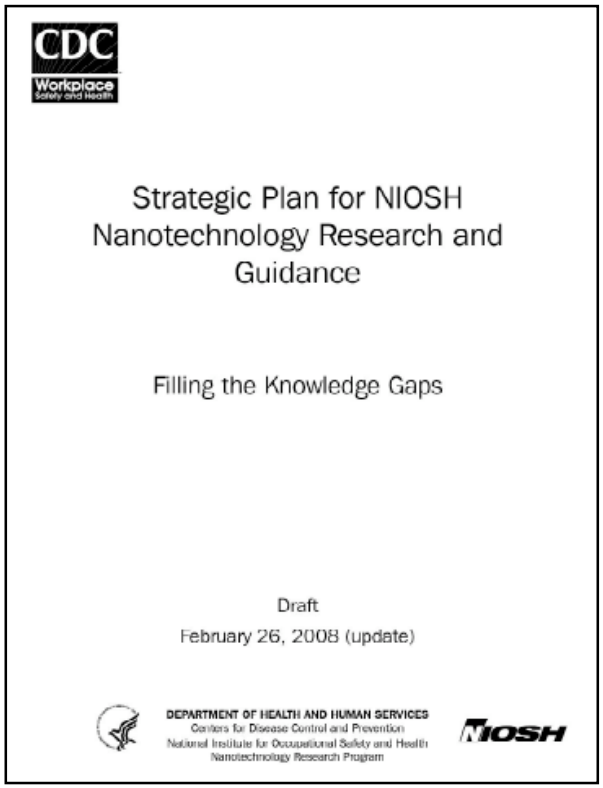
- **Some fabric swatches behave like filter media**
- **Particle penetration driven by pressure differences**
- **Particle penetration is a function of the air permeability of the fabric**
- **FY09 NIOSH research project**



10 cm diameter circular swatch
Single layer of needle-punched Aramid material
TSI 3160; Face velocity = 0.63 cm/sec; Flow rate 1L/min

Where do we go from here?

- **Engineering Controls & PPE**
  - Laboratory studies on efficacy of protective clothing and gloves; complete laboratory studies on respiratory protection
  - Summary of control strategies
  - PPE workplace protection factor (field) studies of nanotechnology workers
- **Applications**
  - Antimicrobial effects on HVAC air and respirator filters
  - Use of monolayer-protected gold nanoparticles in air purifying respirator end of service life indicators


CDC Workplace Safety and Health

Strategic Plan for NIOSH Nanotechnology Research and Guidance

Filling the Knowledge Gaps

Draft

February 26, 2008 (update)

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

NIOSH

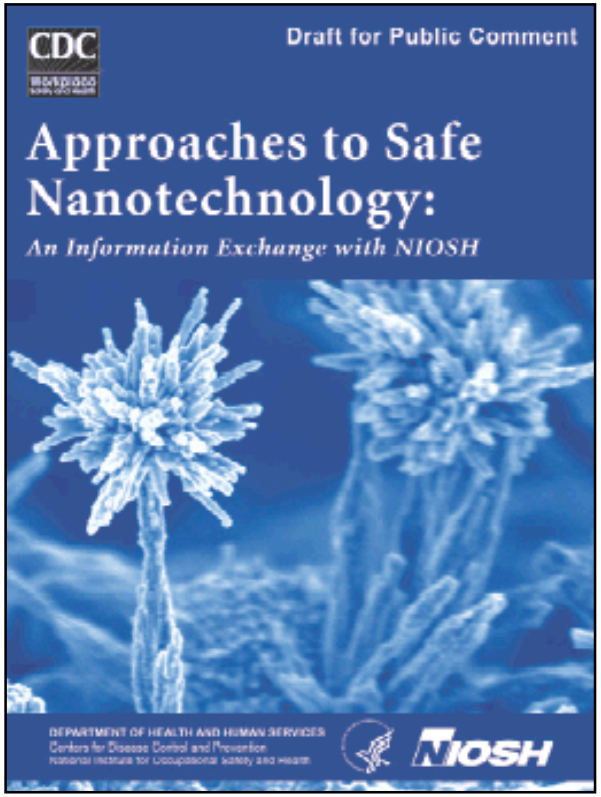
http://www.cdc.gov/niosh/topics/nanotech/pdfs/NIOSH_Nanotech_Strategic_Plan.pdf

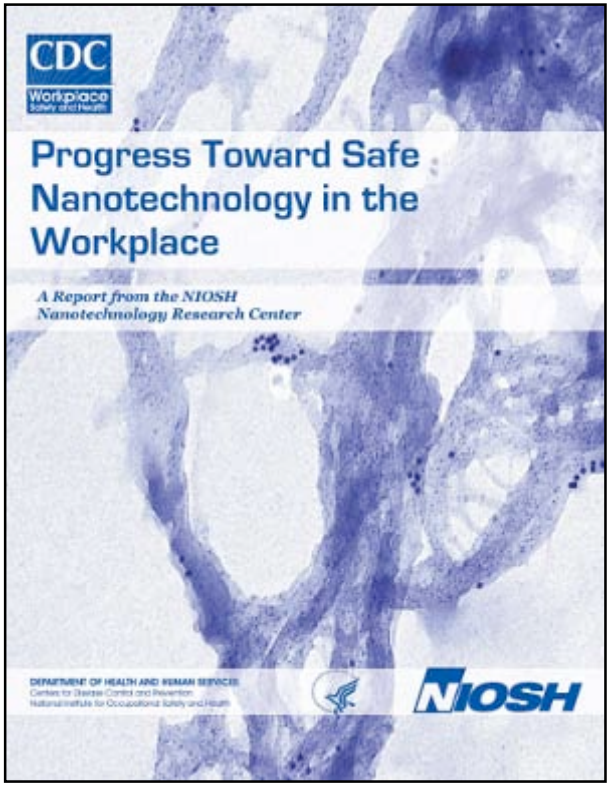
Conclusions

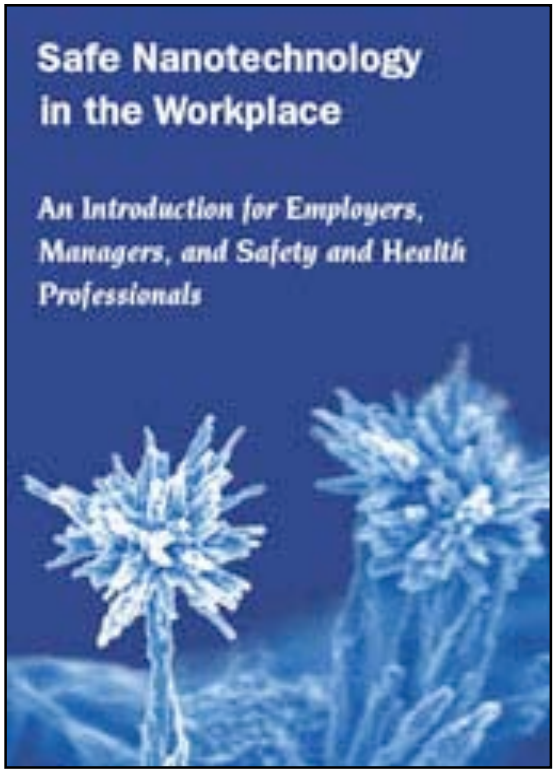
- **NIOSH has an active research program on the control and filtration of nanomaterials**
- **Engineering controls and PPE do minimize workplace exposures, but additional research is still needed to fully understand the limitations**
- **Filters behave as expected - there is no deviation from classical single-fiber theory for particulates as small as 3 nm in diameter**
- **It is likely that NIOSH approved APRs when used in a complete respirator program will be useful for protecting workers from nanoparticle inhalation and should provide levels of protection consistent with their OSHA assigned protection factor (APF)**
- **Research on effectiveness of protective clothing and gloves is just beginning**
- **Nanotechnology can be used to improve control technologies**

How to learn more

Visit the NIOSH Nanotechnology Topic Page
http://www.cdc.gov/niosh/topics/nanotech/







Acknowledgements

- **NIOSH Nanotechnology Research Center (NTRC)**
  - Engineering Controls and PPE co-leader: Jennifer Topmiller
  - Applications: Mark Hoover
- **NIOSH Field Survey Team: Mark Methner, Charles Geraci**
- **Respiratory Protection Team: Samy Rengasamy (PI), Ben Eimer**
- **Protective Clothing Team: Pengfei Gao (PI), Angie Shepherd, Zhong-Min Wang, Peter Jaques**

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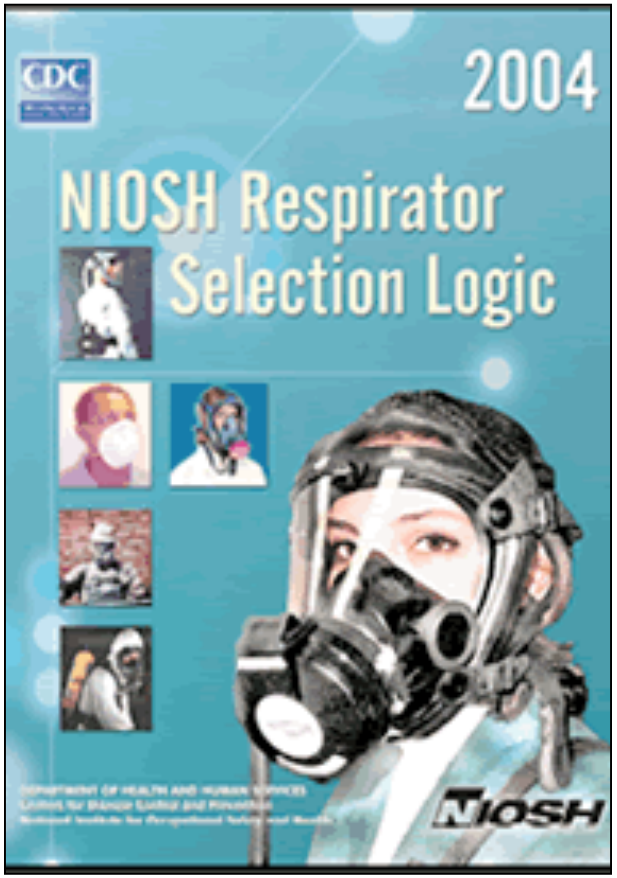
The findings and conclusions in this presentation have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

Thank you

Extra Slides (if needed)

NIOSH Respirator Selection Logic

The purpose of the respirator selection logic is to provide a process that respirator program administrators can use to select appropriate respirators for the protection of workers in specific workplaces.



http://www.cdc.gov/niosh/docs/2005-100/default.html

Assigned Protection Factor (APF)

The workplace level of respiratory protection that a respirator or class of respirators is expected to provide to employees when the employer implements a continuing, effective respiratory protection program as specified in OSHA 29 CFR 1910.134

Reference: Department of Labor, Occupational Safety and Health Administration; Assigned Protection Factors; Final Rule - 71:50121-50192, accessible at http://osha.gov/pls/oshaweb/owadisp.show_document?p_table=FEDERAL_REGISTER&p_id=18846

OSHA APF Values

Type of respirator	Quarter Mask	Half mask	Full facepiece	Helmet/ hood	Loose-fitting facepiece
1 Air-Purifying Respirator	5	10[a]	50	NA	NA
2 Powered APR	-	50	1000	25/1000[b]	25
3 Supplied Airline Respirator	-				
•Demand mode		10	50	NA	NA
•Continuous-flow		50	1000	25/1000[b]	25
•Pressure-demand		50	1000	NA	NA
4 SCBA:	-				
•Demand mode		10	50	50	NA
•Pressure-demand		NA	10,000	10,000	NA

a This APF category includes filtering facepieces, and half masks with elastomeric facepieces.

b Must be demonstrated by Manufacturer that respirator can meet APF of 1,000

Gloves

- **Limited data exists; some organizations recommend double gloving (e.g.,. NanoSafe report)**
- **No standard test for efficacy of gloves against engineered nanomaterials**
- **ASTM test method F1671 for biopenetration of nanometer sized viral particles exists**
  - Phi-X 174 Bacteriophage (27 nm)
  - Pass/fail criteria - < 1 plaque forming unit / ml
  - Used by National Fire Protection Association to certify cleaning gloves and examination gloves used by Emergency Medical Services personnel (NFPA 1999 standard)
  - Used in several studies available in the infection control literature on efficacy of different types of gloves used in hospital settings