WHAT DOES RESPIRATOR CERTIFICATION TELL US ABOUT FILTRATION OF ULTRAFINE PARTICLES?

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Filtration: 42 CR 84.181
- 3 classes, 3 efficiencies
- “Worst case” and “Very Severe”
- Preconditioning, 85 L/min constant flow
- Aerosol size: ~0.3 µm MMAD
- Aerosol charge: Boltzmann charge distribution “Neutralized”
- 95%, 99%, 99.97% N, R, P
Protocols influence measurement

Filtration Efficiency

Challenge aerosol properties

Size, charge distribution

Aerosol measurement method

Photometry

Filter properties

Electret

Test conditions

Protocols influence measurement
What does certification tell us about the filtration of ultrafine particles?
METHODS

- NIOSH challenge aerosols
- Quantifying filtration $\rightarrow$ photometer
- Modeled size-fractioned contributions
- Analyzed in light of most-penetrating size (MPPS)
CHALLENGE AEROSOLS

DOP: CMD 165 nm, GSD 1.6, MMAD ~ 356 nm

CMD = count median diameter
GSD = geometric std deviation
MMAD = mass median aerodynamic diameter

NaCl: CMD 75 nm, GSD 1.86, MMAD ~ 347 nm
AEROSOL MEASUREMENT

- Light scattering photometer before, after filter
- Concentration (mass) ~ photometer response
- Voltages $\rightarrow$ concentration (background corrected)
  
  $$P = \frac{C_{down}}{C_{up}} \times 100\%$$
  
  $P = \%$ penetration

- Limitations: particles $<$ 100 nm poorly detected
AEROSOL MEASUREMENT

Approximate lower limit of photometer response

Particle Diameter (nanometers)

(Fraction/Δln d)

NaCl

DOP
**Model scattered light**

How much does a particle size range contribute to light scatter available for the photometer detection?

\[
R = C_n \int_0^\infty f(d_p)P_\lambda(d_p)d(d_p)
\]

- **Known:**
  - Wavelength incident light
  - Scatter angle
  - Size distribution (upstream)
  - Refractive indices

- **Can:**
  - Model light scatter
  - Fraction by particle size
  - *(ultrafine contribution)*

\( R \) = amount scattered light

\( C_n \) = particle # concentration

\( F(d_p) \) = size distribution function

\( P_\lambda \) = single-particle flux scattered light
LIGHT SCATTER MODEL

- Mieplot 3.5.0.1 – EM scattering, Mie theory
- Single particle flux scattered light, $P_\lambda$
- Multiplied by particle size density function, $f(d_p)$

$$R = \sum_{0nm}^{1000\,nm} f(d_p) P_\lambda(d_p)$$

- Derived “cumulative” function
- Similar to plotting cumulative count, mass
RESULTS - NaCl

The graph shows the cumulative fraction of count, mass, and scatter versus particle diameter in nanometers. The x-axis represents the particle diameter, ranging from 10 to 1000 nanometers, while the y-axis represents the cumulative fraction ranging from 0 to 1.
### RESULTS

**Percent Contribution by Size (NaCl Challenge Aerosol)**

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Count</th>
<th>Mass</th>
<th>Scatter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 100 nm</td>
<td>68</td>
<td>8</td>
<td>0.6</td>
</tr>
<tr>
<td>100 – 200 nm</td>
<td>26</td>
<td>31</td>
<td>8</td>
</tr>
</tbody>
</table>

**Percent Contribution by Size (DOP Challenge Aerosol)**

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Count</th>
<th>Mass</th>
<th>Scatter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 100 nm</td>
<td>10</td>
<td>0.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>100 – 200 nm</td>
<td>47</td>
<td>11</td>
<td>2</td>
</tr>
</tbody>
</table>

- **NaCl** 94% < 200 nm, ~ 8% light scatter
- **DOP** 57% < 200 nm, ~ 2% light scatter
MOST-PENETRATING PARTICLE SIZE

- Influenced by airflow, fiber & aerosol charge
- Certification: MPPS ~ 300 nm MMAD
- Based upon mechanical filtration theory
- May not hold: Electret filters + Boltzmann charged aerosol
Literature: MPPS < 100 nm in certain circumstances

FILTER STUDIES
- Emi et al. 1982
- Baumgartner & Loffler 1986
- Lathrace & Fissan 1986
- Kanaoka et al. 1987

RESPIRATOR STUDIES
- Brosseau et al. 1989
- Stevens & Moyer 1989
- Fardi & Liu 1991
- Martin & Moyer 2000
- Balazy et al. 2006a
- Balazy et al. 2006b
- Richardson et al. 2006
- Eninger et al. 2007

Under NIOSH certification test conditions, MPPS for 95 and 99 class FFR’s is most likely < 100 nm
OBSERVATIONS & CONCLUSIONS

- 42 CR 84.181 respirator filtration certification protocol is limited to providing information on particles > 100 nm in size.

- Certification does not provide users information to aid in selection of RP to protect against ultrafine particles.

- MPPS for certain FFR’s < 100 nm when using NIOSH protocols.
ACKNOWLEDGEMENTS

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