Literature Review of Workplace Breathing Rates & Filter Efficiency Testing under Moderate to High Flow Rates

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15 December 2004
Workplace Breathing Rates

- Objectives
  - Quantify ventilatory parameters based on workplace activities
  - Review literature and analyze compiled data to quantify impacts of respirators on ventilation
Workplace Breathing Rates

- Literature review published Sep 04 (ECBC-TR-0316)
- Limited empirical data to meet objectives

- Adopted approach for estimating minute volumes from energy expenditure literature
  - Exponential functions utilized to estimate minute volume ($V_E$) from energy expenditure literature when $V_E$ not reported

- Predictions of peak flow rates
  - Based on linear relationship ($R^2 = 0.82, p < 0.001$) between $V_E$ and PIF for individual subject data and prediction intervals
  - Range of PIF based on $V_E$
Estimation of Minute Volume

![Graph showing the relationship between Oxygen Consumption (L·min⁻¹) and Minute Volume (L·min⁻¹)]

- Baba et al. (2002)
Estimation of PIF Rates

$y = 3.19x + 4.49$

$R^2 = 0.82$

$V_E (L \cdot min^{-1})$

PIF (L \cdot min^{-1})
$V_E$ Distribution for Work Tasks

![Histogram showing the distribution of minute volume (L/min).]
Workplace Breathing Rates

- **Minute volume distribution**
  - Mean = 38.5 \pm 16.6 \text{ L}\cdot\text{min}^{-1} (n = 565)
  - Median = 33.6 \text{ L}\cdot\text{min}^{-1}
  - 95\text{th} percentile = 73.3 \text{ L}\cdot\text{min}^{-1}
  - Peak = 162 \text{ L}\cdot\text{min}^{-1}

- **PIF ranges**
  - Mean $V_E$: 72 to 183 \text{ L}\cdot\text{min}^{-1}
  - 95\text{th} percentile $V_E$: 182 to 295 \text{ L}\cdot\text{min}^{-1}
  - Peak $V_E$:
    - Estimation not valid for $V_E$ over \sim 120 \text{ L}\cdot\text{min}^{-1}
    - Peak $V_E$ in range (\sim 102 \text{ L}\cdot\text{min}^{-1}): 273 to 389 \text{ L}\cdot\text{min}^{-1}
Peak Human Performance

- **Maximal $V_E$**
  - Males (20-29 yr) = $114 \pm 23 \text{ L} \cdot \text{min}^{-1}$
  - Females (20-29 yr) = $87 \pm 17 \text{ L} \cdot \text{min}^{-1}$
  - Extremes of 180 to 200 $\text{L} \cdot \text{min}^{-1}$

- **Peak flow rates**
  - Maximum exercise values $\sim 300 \text{ L} \cdot \text{min}^{-1}$
  - Peak in-house value $\sim 485 \text{ L} \cdot \text{min}^{-1}$ during hard work
  - Extremes of 500+ $\text{L} \cdot \text{min}^{-1}$ reported
Summary of Workplace $V_E$

- **Occupational $V_E$ rarely approach $V_{E \text{ max}}$ values**
  - 73 L·min$^{-1}$ sufficiently represents the upper limit of minute volumes anticipated in the workplace
  - 114 L·min$^{-1}$ reasonable estimate for $V_{E \text{ max}}$

- **Peak inspiratory flows**
  - High end predictions based on $V_E$ correspond with literature
  - Suggest upper limit of 430 L·min$^{-1}$ based on $V_{E \text{ max}}$ of 114 L·min$^{-1}$

- **Higher $V_E$ and peak flows will occur!**
  - Literature suggests such instances are not the norm
Analysis of Respirator Data

• **Objectives**
  - Validate/update current knowledge on ventilation during respirator wear
  - Identify data gaps for further research

• **Status**
  - Gathered human ventilation data from 4 sources
  - Database variables defined and populated
  - Analysis of data initiated October 2004
  - Anticipate completion January 2004; report to follow
Preliminary Findings
Preliminary Findings

![Box plot diagram showing PIF (L/min) vs. Inhalation resistance (cmH2O/L/s). The mean is denoted with a red line.](image-url)
Filter Efficiency Testing

- Objectives
  - Assess effect of moderate to high flows on performance of NIOSH-approved particulate respirator filters
  - Compare efficiencies measured under constant and cyclic flow conditions
  - Compare efficiencies measured using inert and bioaerosol challenges
Test Materials

- Test filters
  - Eight NIOSH-approved N95 and P100 respirator filters
  - Non-powered APR particulate filters
- Cartridges: 2 N95 and 2 P100
- Filtering facepieces: 2 N95 and 2 P100

Challenge Aerosols

- Inert particles: 0.02 to 3 μm
- N95: NaCl, polystyrene latex spheres
- P100: DOP, Emery 3004
- Bioaerosols:
- Bacterial: Bg spores
- Viral: MS2 phage
# Test Parameters

<table>
<thead>
<tr>
<th>Flow Condition</th>
<th>Minute Volume(^{(a)}) (L/min)</th>
<th>Tidal Volume (L)</th>
<th>Breathing Rate (#/min)</th>
<th>PIF(^{(b)}) (L/min)</th>
<th>MIF(^{(c)}) (L/min)</th>
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</table>

(a) Minute volume halved when testing single cartridge from dual cartridge respirator

(b) Peak Inspiratory Flow

(c) Mean Inspiratory Flow
Test Parameters

- Cyclic flow conditions based on Workplace $V_E$ review and analysis
  - 40 L·min$^{-1}$: mean $V_E = 38.5$ L·min$^{-1}$
  - 85 L·min$^{-1}$: current test flow parameter
  - 115 L·min$^{-1}$: average $V_{E_{max}} = 114$ L·min$^{-1}$
  - 135 L·min$^{-1}$: $V_{E_{max}} + 1SD = 137$ L·min$^{-1}$
Preliminary Findings

- Effect of flow rate and particle size on measured penetration through a P100 cartridge.
Preliminary Findings

Comparison of penetrations measured under constant and cyclic flow conditions through a P100 cartridge.
Test Status

• **Inert submicron aerosol**
  – Testing complete
  – Initiated “large” particulate testing (0.7, 1.3, 3.0 μm)
  – Anticipate completion in February 2005

• **Bioaerosol testing**
  – Cartridge tests completed with Bg spore challenge
  – Initiated filtering facepiece Bg testing
  – MS2 phage testing will commence following Bg trials
  – Testing scheduled for completion in April 2005
Future Directions

- **Workplace breathing & respirator ventilation data**
  - Update findings based on any new found information
  - Evaluate human breathing during occupational task performance

- **Filter testing**
  - Study combination filters/CBRN filters
  - Determine filtration efficiency based on waveshapes and/or breathing profiles

- **Other**
  - Human factors review of CC SCBA