The NIOSH Ventilated Headboard

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Toxicology Refresher (from an engineer!)

- **Dose:**
  - Airborne Dose = Airborne concentration x time x inhalation rate
  - Surface Contamination (from Infectious Aerosols):
    - \( f(x) \): \{concentration, settling rates, and time between cleansings\}
  - Common variables: **Concentration & Time**
- Today’s discussion will focus on both the **Concentration & Time** variables.
Hierarchy of Controls

Most effective

Elimination
- Physically remove the hazard

Substitution
- Replace the hazard

Engineering Controls
- Isolate people from the hazard

Administrative Controls
- Change the way people work

PPE
- Protect the worker with Personal Protective Equipment

Least effective

Source: https://www.cdc.gov/niosh/topics/hierarchy/default.html
Airborne Infection Isolation Rooms (AIRs)

- Dedicated single-patient room
- At least 12 air changes per hour (ACH) total ventilation (6 ACH if pre-2001), including min. 2 ACH outside air
- Maintained at negative pressure relative to adjacent areas (-0.01 inches water gauge, or 2.5 Pa)
- All seams & penetrations sealed
- All air exhausted to outdoors, (CDC: unless HEPA-filtered and returned to dedicated HVAC system)
- Portable High Efficiency Particulate Air (HEPA) fan/filter systems can be used to increase effective ACH of air cleaning

References: ASHRAE Standard 170, CDC 2005 TB Guidelines, CDC Environmental Infection Control Guidelines
The Problem

• Large hospitals typically have limited number of engineered AI rooms

• Small hospitals may have 1 engineered AI room

• There is essentially NO engineered surge capacity in case of epidemic (natural or intentional)

• Non-hospital medical, social service facilities, and health departments generally lack isolation capabilities
Nation’s capacity improved (since 09/11) but gaps in preparedness remain. Level of preparedness varied across jurisdictions.

“..many hospitals lack capacity to respond to large scale infectious disease outbreaks.”

“..most hospitals lack adequate equipment, isolation facilities, and staff…”

“...initial response to an outbreak of infectious disease would occur at the local level...”
Typical Surge Response Plans:

- Patient transfer
- Big-area iso (hot) zones with patient cohorting (worker unfriendly)
- Respirators and surgical masks with traditional patient rooms
- Shut patient room door and hope that existing dilution ventilation system is sufficient.
- Dilution Filtration with Portable HEPA units to achieve equivalent 12 ACH
ACH vs Clearance Time Determination

- Estimates wait time required to enter room for cleaning following occupancy by patient potentially generating infectious aerosols

- Affects room turnover wait period between patients

- AllIRs have significant waits – Non-AllIRs generally have longer waits
**ACH vs Clearance Time Determination**

1. **Airborne Contaminant Removal**

   **Table B.1.** Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency *

<table>
<thead>
<tr>
<th>ACH 5</th>
<th>Time (mins.) required for removal 99% efficiency</th>
<th>Time (mins.) required for removal 99.9% efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>138</td>
<td>207</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
<td>104</td>
</tr>
<tr>
<td>6$^+$</td>
<td>46</td>
<td>69</td>
</tr>
<tr>
<td>8</td>
<td>35</td>
<td>52</td>
</tr>
<tr>
<td>10$^+$</td>
<td>28</td>
<td>41</td>
</tr>
<tr>
<td>12$^+$</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>15$^+$</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>20</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

* This table is revised from Table 53-1 in reference 4 and has been adapted from the formula for the rate of purging airborne contaminants presented in reference 1435.

ACH vs Clearance Time Determination

- **Table B-1 Footnotes** (2003 Infection Control Guidelines)
  - This table is revised from Table S3-1 in reference 4 and has been adapted from the formula for the rate of purging airborne contaminants presented in reference 1435.
  - The times given assume perfect mixing of the air within the space (i.e., mixing factor = 1). However, perfect mixing usually does not occur. Removal times will be longer in rooms or areas with imperfect mixing or air stagnation. Caution should be exercised in using this table in such situations.

**Table S3-1 Footnotes** (CDC’s 1994 TB Guidelines)

The times given assume perfect mixing of the air within the space (i.e., mixing factor = 1). However, perfect mixing usually does not occur, and the mixing factor could be as high as 10 if air distribution is very poor (98). The required time is derived by multiplying the appropriate time from the table by the mixing factor that has been determined for the booth or room.
### Dilution Wait Times for Desired Removal Efficiency

<table>
<thead>
<tr>
<th>ACH</th>
<th>Minutes Required for the Desired Removal Efficiency</th>
<th>90%</th>
<th>99%</th>
<th>99.9%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>69, 138, 207</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>23, 46, 69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>12, 23, 35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assuming the aerosol source is stopped and a good dilution ventilation design (K=3), it will take 69 minutes (3 x 23) to achieve a 99% dilution of airborne particulate (assumes 100% of reduction is via dilution).

For a room with 12 ACH and good air movement, *three* can be assumed as the mixing factor. The equation for the dilution factor is:

\[
C_2 = C_1 e^{-\frac{Q \Delta t}{V}}
\]

\[
\Delta t = -\frac{V}{Q} \ln \left( \frac{C_2}{C_1} \right)
\]
Expedient Methods for Patient Isolation During Natural or Manmade Epidemic Response

**Purpose**: To ID & evaluate effective parameters for patient isolation and healthcare worker protection to meet airborne isolation surge requirements during bioterrorism or epidemic emergency events:

*Basically looking for a cheap, easy, quick, yet effective method for reducing infectious aerosol concentrations and potential exposures to healthcare workers.*
Alternative Approaches

• Reduce volume of contaminated zone
  – Effectively increases ACH w/in contaminated zone for a given flow rate

• Use local control techniques
  – Captures and removes contaminant before it has a chance to disperse.
    – Reduces the required time for the overall room to achieve a desired removal efficiency.
Local Control Design Considerations

• Local Exhaust Ventilation (LEV)
  – ACGIH – 50-100 fpm capture velocity across source (low momentum, still air)
  – “Source” is patient’s nose/mouth

• ASHRAE Standard 55 - *Thermal Environmental Conditions for Human Occupancy*
  – Seeks 80%+ acceptability
  – Percent Dissatisfied (PD) equation based on wind speed, temp, and turbulence
  – At 75 degF and low-mod. turbulence, PD = 15-20% at V = 30-37 fpm.
Alternative Capture Velocity Approach

- **Increase Enclosure**
  - Protects source from crosswind interference

- **Unidirectional flow within enclosure**
  - Nearly eliminates turbulent diffusion of contaminant
  - Minor disruptions are quickly overcome by unidirectional flow

Photo Credit: CDC/NIOSH
Expedient Isolation

- Simple wooden “hood” can be built for approx. $50.00 and is used with existing HEPA air cleaners
- Can be very effective (see before/after graphs)
- During testing: Protection factors ranged from 77 - 1000 (Note: The APF for an N95 respirator = 10)
Portable Air Cleaners

- High efficiency particulate air (HEPA) fan/filter units
- HEPA = 99.97% efficient at 0.3 microns, even greater efficiency at other size ranges both smaller and larger than 0.3 microns.
- Human-generated infectious aerosol generally 1 um and larger.
- HEPA filtered air = clean outdoor air (from infectious aerosol perspective)
- Can also be used to augment Pressurization, Directional Airflow, and *Direct Source Capture control techniques*. 
Portable Air Cleaners

Photos Sourced By: CDC/NIOSH
Aerosol Generation/Measurement
1. A control-off condition with HEPA off and no hood in position

2. A control-on condition with HEPA activated and the hood enclosure extended to provide a hood depth of $D_o$
   - Qualitative smoke tests using handheld smoke generator were used to identify a minimum effective hood depth ($D_o$) at each location.

3. A second control-on condition with HEPA activated and the hood extended to provide a hood depth of $D_o + 8”$
   - $D_o + 8”$ approximated a 75% of largest dimension rule-of-thumb from Industrial ventilation
Results
Ventilated Headboard (1-bed) 
VA Medical Center (VAMC) 
OKC, OK

Room
Volume = 970 cu-ft
Room
Area = 121 sq-ft

Sample location

Source location

Restroom
(Qe = 45 cfm)

Qs = 60 cfm

Qe = 100 cfm
Anteroom

(Q = 240 cfm)

HEPA

Qs = 80 cfm
(after deflection)

Qe = 0 or 118 cfm

VA Medical Center Room 6B-117
1 Bed, Oklahoma City, OK

Entrance
Ventilated Headboard (1-bed)
VA Medical Center (VAMC)
OKC, OK

Grimm Aerosol Counts
GMean Reduction Ratios
2:1 / 3:1

Qs = 60 cfm
Qe = 100 cfm
Anteroom

Room
Area = 121 sq-ft
Room
Volume = 970 cu-ft

Sample location
Source location

Restroom
(Qe = 45 cfm)

99/.99

1.0/1.0
(Q = 240 cfm)

Qs = 80 cfm
(after deflection)

99/.99

1.0/1.0

99/.99

99/.99

Qe = 0 or 118 cfm

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99/.99

99/.99

99/.99

Qe = 0 or 118 cfm
Ventilated Headboard (1-Bed)
Central KS Medical Center (CKMC)
Great Bend, KS

Sample locations (Grimm & IH)

Source generation points

Rm 524, 1-Bed: Great Bend, KS

A
B
C
D
E
HEPA

Q_{exh} = 0

Q_s = 138 cfm
90 CV + 48 induced recirc.)
Ventilated Headboard (1-Bed)  
Central KS Medical Center (CKMC)  
Great Bend, KS

Sample locations (Grimm & IH)

Source generation points

Grimm Aerosol Counts  
GMean Reduction Ratios  
2:1 / 3:1
Ventilated Headboard (1-bed), ST Joseph Memorial Hospital (SJMH)
Larned, KS

Recirc. Unit 128 cfm on high setting

Temp. test wall

Wall “door” closed during tests

6”x6” O.A. supply = 40 cfm

Qexh = 0 cfm

Sample positions (Grimms & IH)

Dosing positions
Recirculation Unit 128 cfm on high setting

A T B
D HEPA

Temp. test wall

Wall “door” closed during tests

6"x6" O.A. supply = 40 cfm

Qexh = 0 cfm

Entrance

Ventilated Headboard (1-bed), ST Joseph Memorial Hospital (SJMH) Larned, KS

Sample positions (Grimms & IH)

Grimm Aerosol Counts Gmean Reduction Ratios 2:1/3:1

Dosing positions

Recirc. Unit 128 cfm on high setting
Sample positions (Grimms & IH)

Dosing positions
Ventilated Headboard (1-Bed)
INTEGRIS Baptist Medical Center (IBMC), OKC, OK

Sample positions (Grimms & IH)

Dosing positions

Grimm Aerosol Counts
Gmean Reduction Ratios
2:1/3:1

Exterior window
Corridor
TV Shelf
Retractable Partition
(Leads to adjacent sitting area)
Summary of GMRRs and lower limits (in parentheses) for the Ventilated Headboard (1-Bed) expedient isolation field studies, aerosol spectrometer data simultaneously–corrected for $\alpha = 0.10$

(Bold Red font = GMRR <90%)

<table>
<thead>
<tr>
<th>Hospital Sample Pos.</th>
<th>VAMC 2:1</th>
<th>3:1</th>
<th>CKMC 2:1</th>
<th>3:1</th>
<th>SJMH 2:1</th>
<th>3:1</th>
<th>IBMC 2:1</th>
<th>3:1</th>
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<tr>
<td>HCW-RHS</td>
<td>0.987</td>
<td>0.996</td>
<td>0.999</td>
<td>0.997</td>
<td>0.998</td>
<td>0.997</td>
<td>0.998</td>
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<tr>
<td></td>
<td>(0.947</td>
<td>0.979)</td>
<td>(0.996</td>
<td>0.991)</td>
<td>(0.996</td>
<td>0.995)</td>
<td>(0.990</td>
<td>0.993)</td>
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<td>HCW-LHS</td>
<td>0.997</td>
<td>0.996</td>
<td>0.998</td>
<td>0.998</td>
<td>0.998</td>
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<tr>
<td></td>
<td>(0.986</td>
<td>0.980)</td>
<td>(0.995</td>
<td>0.993)</td>
<td>(0.996</td>
<td>0.997)</td>
<td>(0.997</td>
<td>0.994)</td>
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<tr>
<td>Patient chest</td>
<td>1.00</td>
<td>1.00</td>
<td>0.967</td>
<td>0.920</td>
<td>0.998</td>
<td>0.997</td>
<td>1.00</td>
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<tr>
<td></td>
<td>(1.00</td>
<td>0.998)</td>
<td>(0.898</td>
<td>0.724)</td>
<td>(0.997</td>
<td>0.995)</td>
<td>(1.00</td>
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<td>Patient feet</td>
<td>0.995</td>
<td>0.997</td>
<td>0.996</td>
<td>0.993</td>
<td>0.996</td>
<td>0.997</td>
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<td>0.984)</td>
<td>(0.989</td>
<td>0.977)</td>
<td>(0.993</td>
<td>0.995)</td>
<td>(0.990</td>
<td>0.993)</td>
</tr>
<tr>
<td>Center Room</td>
<td>0.997</td>
<td>0.996</td>
<td>0.997</td>
<td>0.996</td>
<td>0.997</td>
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<tr>
<td></td>
<td>(0.988</td>
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<td>(0.990</td>
<td>0.985)</td>
<td>(0.995</td>
<td>0.996)</td>
<td>(0.994</td>
<td>0.989)</td>
</tr>
</tbody>
</table>
**Expedient Isolation Protection Factor (EIPF)**

- A surrogate measure of the workplace protection
- Analogous to Simulated Workplace Protection Factor (SWPF) used by NIOSH in respirator testing.
- EIPF can be calculated by:

\[
EIPF = (1 - GMRR)^{-1.0}
\]
Expedient Isolation Protection Factor (EIPF)

Ventilated Headboard Configuration

- GMRRs = 1.0 must be carried out to true value (<1) for EIPF formula to apply
- Across four study sites, Center Room and worker positions:

Mean EIPF = 338 (77-1000*)

*8-100 times OSHA’s N95 APF of 10
Current isolation guidance does not adequately address bioterrorism and epidemic response needs at the local level.
• Shortages of isolation capacity may impede the medical response to an emergency
• Current trends in surge iso design do not sufficiently address worker protection issues
• Expedient in-room isolation units employing high-flow HEPA filtration offer an alternative to emergency AIIs that is:
  - Affordable  
  - Available  
  - Effective  
  - Fast to set up
Subsequent Developments

- Design Improvements:
  - Retractable canopy
  - DIY wood version (approx $50) – detailed instructions
  - Extruded aluminum model/kit
    - Approx. $800/$1000
    - Adjustable for hospital beds, gurneys, or emergency cots
- Alternate Care Scenarios: Multi-beds/
- Mobile Isolation Hood
- Ventilated Headboard + Isolation “Tent” = 2 layers of protection
- Protective Isolation
- Instructional/Demo videos
- CFD Modeling
- NIOSH Blog: lots of links, detailed instructions, videos
Design Improvements

- “Wooden” prototype redesigned into DIY ($50) and extruded aluminum models.
- Lightweight, sturdy, easier to store/ship. Applicable to pre-planned emergency surge response kits.
- Height is adjustable to accommodate varying cot/bed heights.
- Coordinated with parts manufacturers to result in current order capability of expedient airborne isolation (EAI) hood as a single line item, available in kit or preassembled form.

Commercially-available expedient airborne isolation hood shown without canopy in place.

Photo Credit: CDC/NIOSH
5-bed iso kit built with Aluminum Design

NOTE: Blue-topped tent in background used to demonstrate 2-layers of iso protection by placing EAI hood within negative pressure tent enclosure

Photo Credits: CDC/NIOSH
Mobile Iso Hood “Crash Cart”

- Stored at designated charging station when not in use and wheeled into place when needed.

- Built-in fan/filtration (i.e. no ductwork!)

- Operates on traditional 115v power but capable of 90-minute operation on built-in battery power. (Buys time to arrange transport or run extension cord)

- Can be paired with solar/wind power sources for operation in austere environments without reliant power grid.

Image/Photo Credit: CDC/NIOSH
Alternative Application: Protective ("Reverse") Isolation

- Tested in this configuration following Japanese Tsunami & Fukushima Nuclear Incident.
- Emergency method for developing surge capacity in protective (reverse isolation) environments.
- Prescribed for patients who are immunosuppressed due to radiation exposure.
- Direction of filtered airflow is reversed from Airborne Infectious Isolation mode, providing positive pressure protective isolation.
- “Fit Test” protection factor > 15000
- ISO Class 5 Cleanroom Condition Under Hood (equivalent to that req’d for sterile pharmacy compounding)

CDC/NIOSH Photo Showing Ventilated Headboard Tested In Reverse Isolation Mode:
NIOSH Ventilated Headboard Provides Solution to Patient Isolation During an Epidemic

To protect healthcare workers, other patients, and visitors from exposure to airborne infectious diseases, patients in hospital settings sometimes need to be placed in airborne infection isolation rooms (AIIRs). AIIRs contain specific engineering features to isolate and more quickly remove potentially infectious patient aerosols so that they do not infect others. Isolation rooms are expensive, costing about $10,000 more to construct than a typical patient room. As a result, not all facilities have isolation rooms or have enough isolation rooms to handle an epidemic proportion.

To address the need for multiple isolation rooms, the National Institute for Occupational Safety and Health (NIOSH) developed the Ventilated Headboard to isolate patients while protecting healthcare personnel from airborne infectious diseases. The ventilated headboard is inexpensive, easy to erect, safe, and scientifically proven.

The ventilated headboard consists of lightweight, sturdy, and adjustable aluminum framing with a retractable plastic canopy. The ventilated headboard is not a filtration system in itself, rather it is a special inlet system designed to provide a strategically improved air media for a cost-effective, high-efficiency particulate air (HEPA) filter unit. Together, the ventilated headboard and HEPA system can provide multiple isolation units or surge isolation capacity in traditional patient rooms, triage stations, emergency medical shelters, or as an emergency temporary support option for displaced population shelters.

- The ventilated headboard provides near-instant capture of patient-generated aerosol.
- Laboratory tests show the capture and removal of over 90% of airborne infectious-sized aerosol.
- The retractable canopy allows for hands-on healthcare procedures while still providing protection to attending healthcare personnel.
- The canopy allows lower-velocity air currents to capture/remove contaminants without interrupting the patient.
- The canopy material (plastic sheeting) is held in place by removable retenant cups and can easily be replaced between patients.
- In addition to the direct capture capabilities of the ventilated headboard, the HEPA filtration system provides continuous air cleaning to the surrounding room air.

NIOSH researchers have constructed and tested the ventilated headboard in two general configurations: (1) a wooden, do-it-yourself model constructed from supplies found at your local hardware store and (2) a lightweight aluminum model that can be manufactured by a machine shop. For more information, please see the original blog post.

Source: CDC/NIOSH (https://blogs.cdc.gov/niosh-science-blog/2020/04/14/ventilated-headboard/)
Questions?

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kmead@cdc.gov

For more information, contact CDC
1-800-CDC-INFO (232-4636)

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