National Institute for Occupational Safety and Health

The NIOSH Ventilated Headboard

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By: Kenneth R. Mead Ph.D., PE
Division of Field Studies and Engineering
National Institute for Occupational Safety and Health
Centers for Disease Control and Prevention

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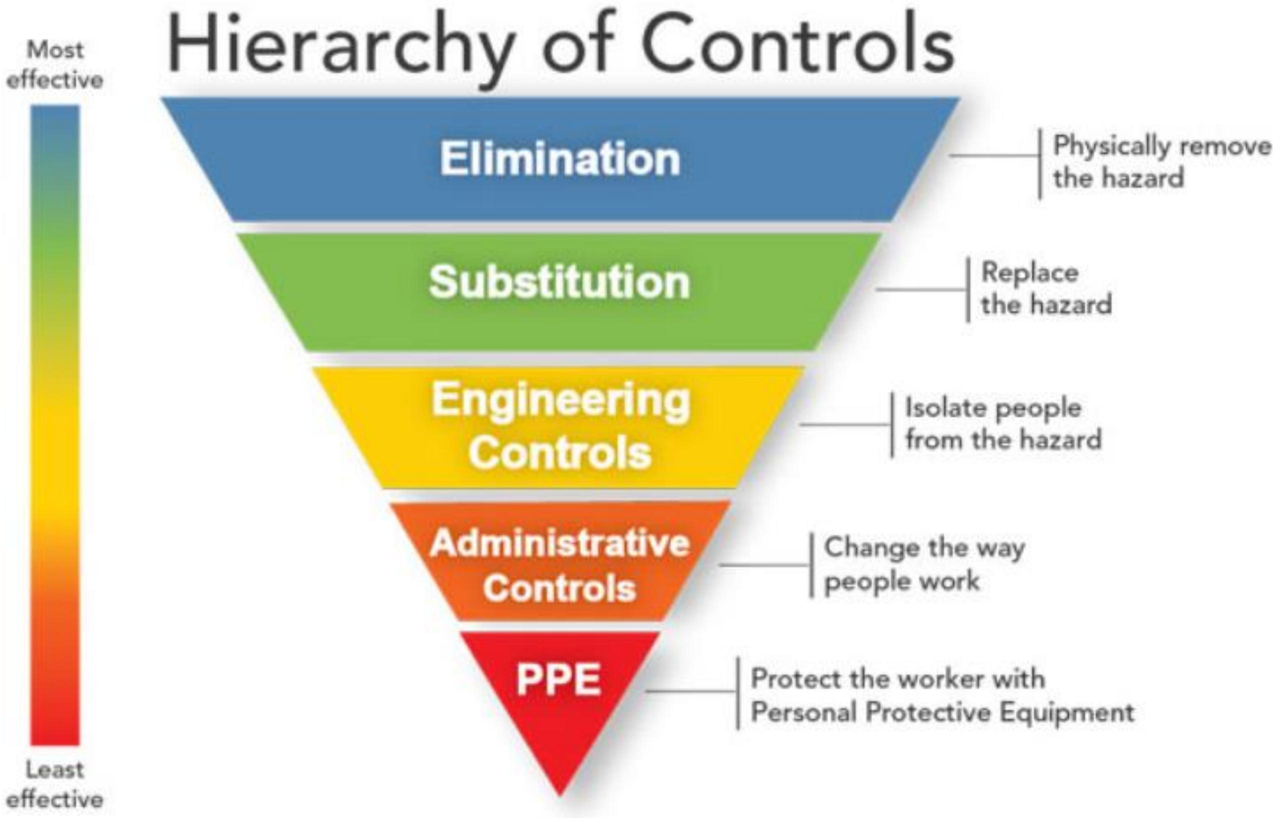
Toxicology Refresher (from an engineer!)

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



Source: https://www.cdc.gov/niosh/topics/hierarchy/default.html

Airborne Infection Isolation Rooms (AIIRs)

- 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 AII rooms
- Small hospitals <u>may</u> have 1 engineered AII 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

GAO Report/Testimony: April 2003

(A historical perspective?)

- 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
- AIIRs have significant waits – Non-AIIRs 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 *

ACH § ¶	Time (mins.) required for removal 99% efficiency	Time (mins.) required for removal 99.9% efficiency
2	138	207
4	69	104
6[+]	46	69
8	35	52
10[+]	28	41
12[+]	23	35
15[+]	18	28
20	14	21
50	6	8

* 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.

Source: CDC Environmental Infection Control Guidelines (2003)

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

ACH	Minutes Required for the Desired Removal Efficiency		
	90%	99%	99.9%
2	69	138	207
6	23	46	69
12	12	23	35

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).

three can be assumed for a room with 12 ACH and good air movement.).

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

$$\Delta t = -\left(\frac{V}{Q}\right)\ln(C_2 / C_1)$$

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

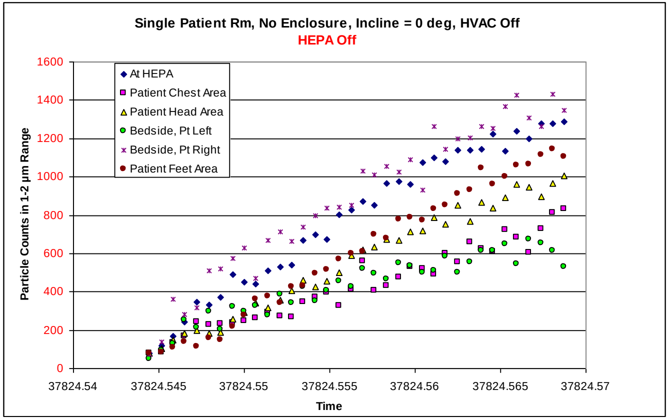
- Local Exhaust Ventilation (LEV)
  - ACGIH – 50-100 fpm capture velocity across source (low momentum, still air)
  - “Source” is patient’s nose/mouth
- ASHRAE Standard 55 - *Thermal Environmental Conditions for Human Occupancy*
  - Seeks 80%+ acceptability
  - Percent Dissatisfied (PD) equation based on wind speed, temp, and turbulence
  - At 75 degF and low-mod. turbulence, PD = 15-20% at V = 30-37 fpm.

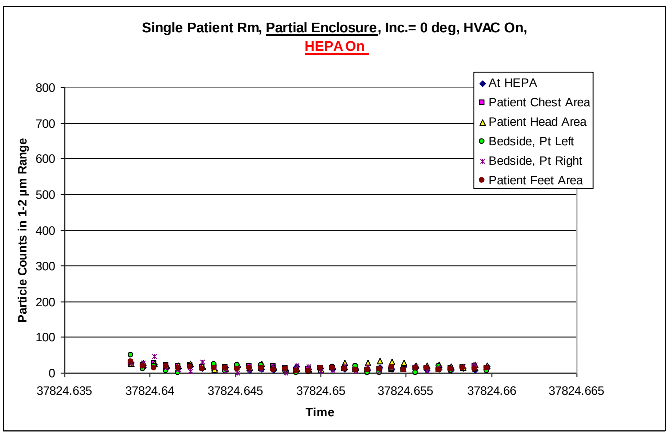
Alternative Capture Velocity Approach

- 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)

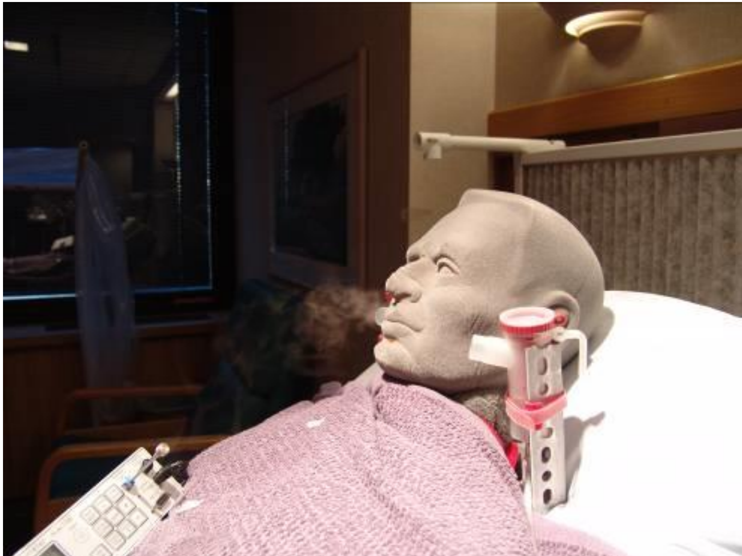
Portable Air Cleaners

- 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



Ventilated Headboard Test Conditions

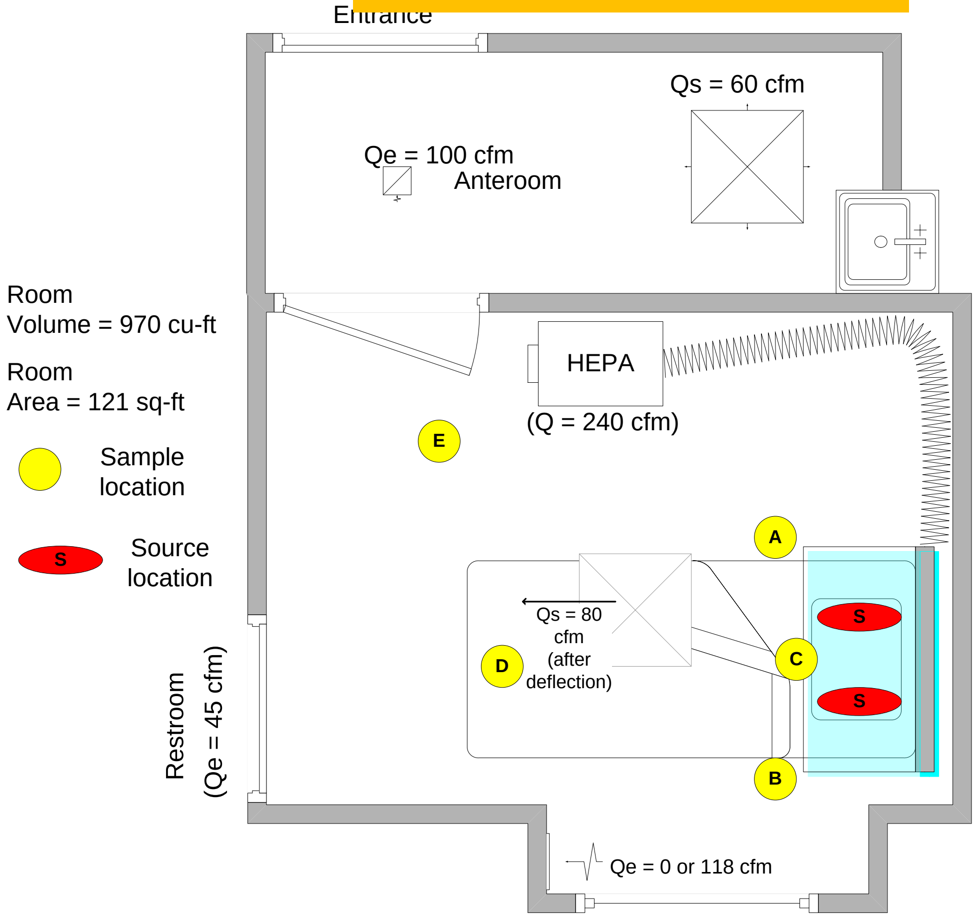
1. A control-off condition with HEPA off and no hood in position

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

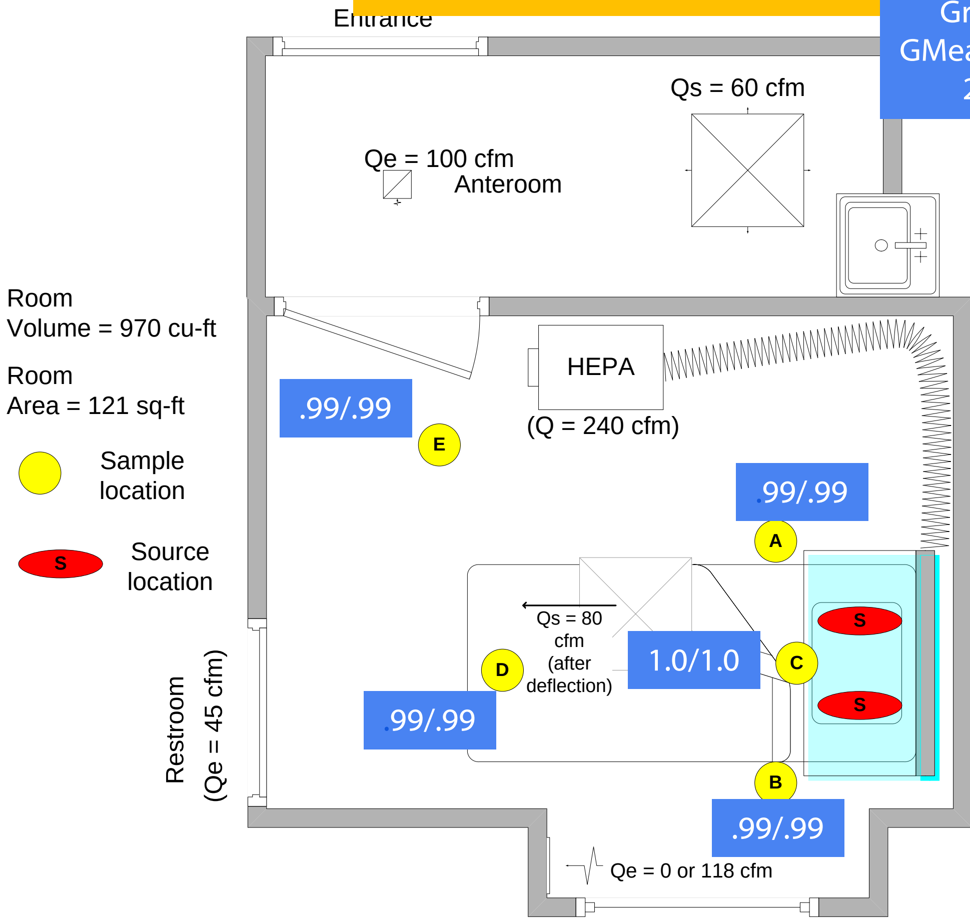
Results

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

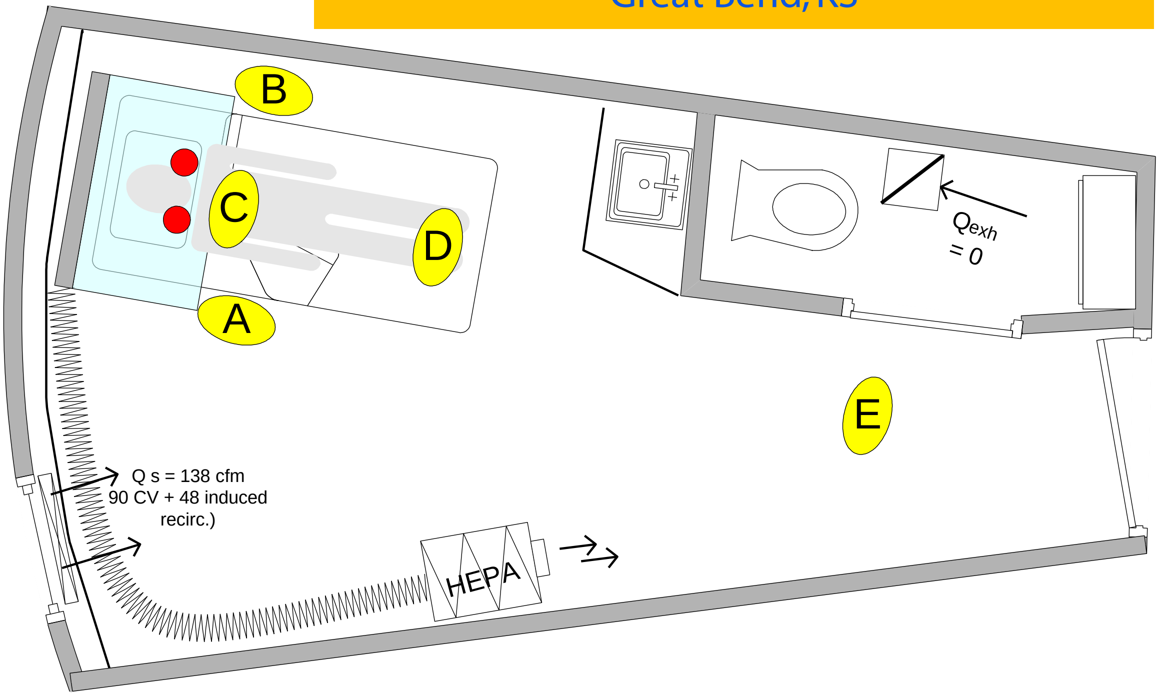


Ventilated Headboard (1-bed)
VA Medical Center (VAMC)
OKC, OK

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



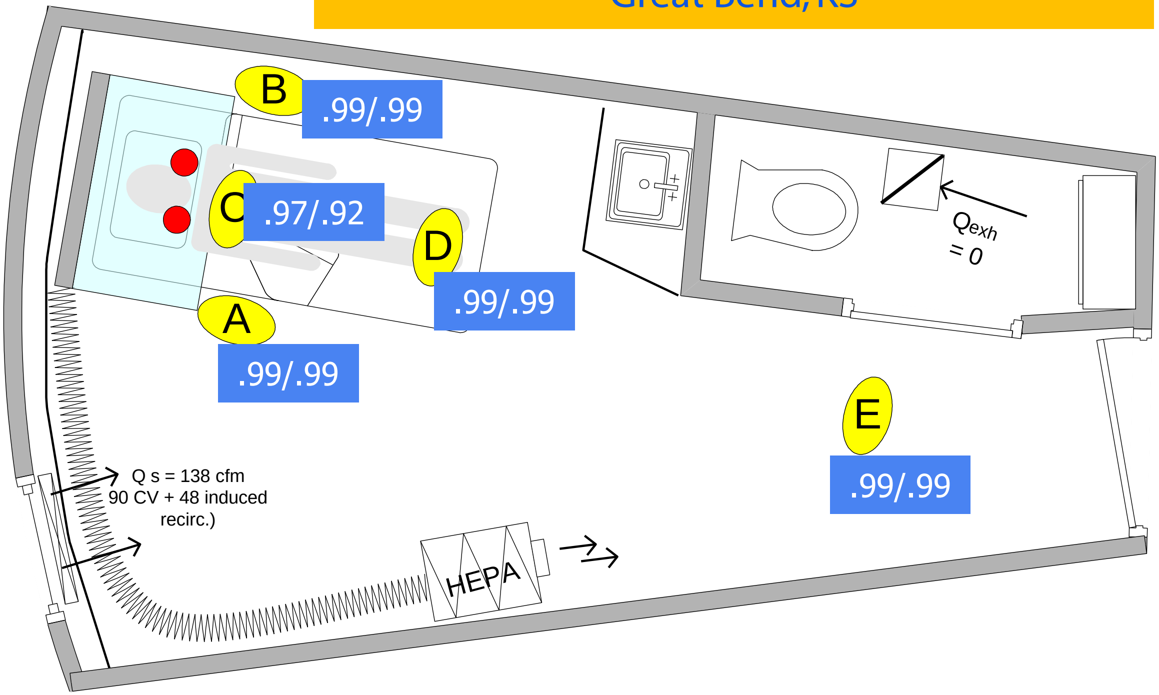
Ventilated Headboard (1-Bed)
Central KS Medical Center (CKMC)
Great Bend, KS



Sample locations (Grimm & IH)

Source generation points

Ventilated Headboard (1-Bed)
Central KS Medical Center (CKMC)
Great Bend, KS

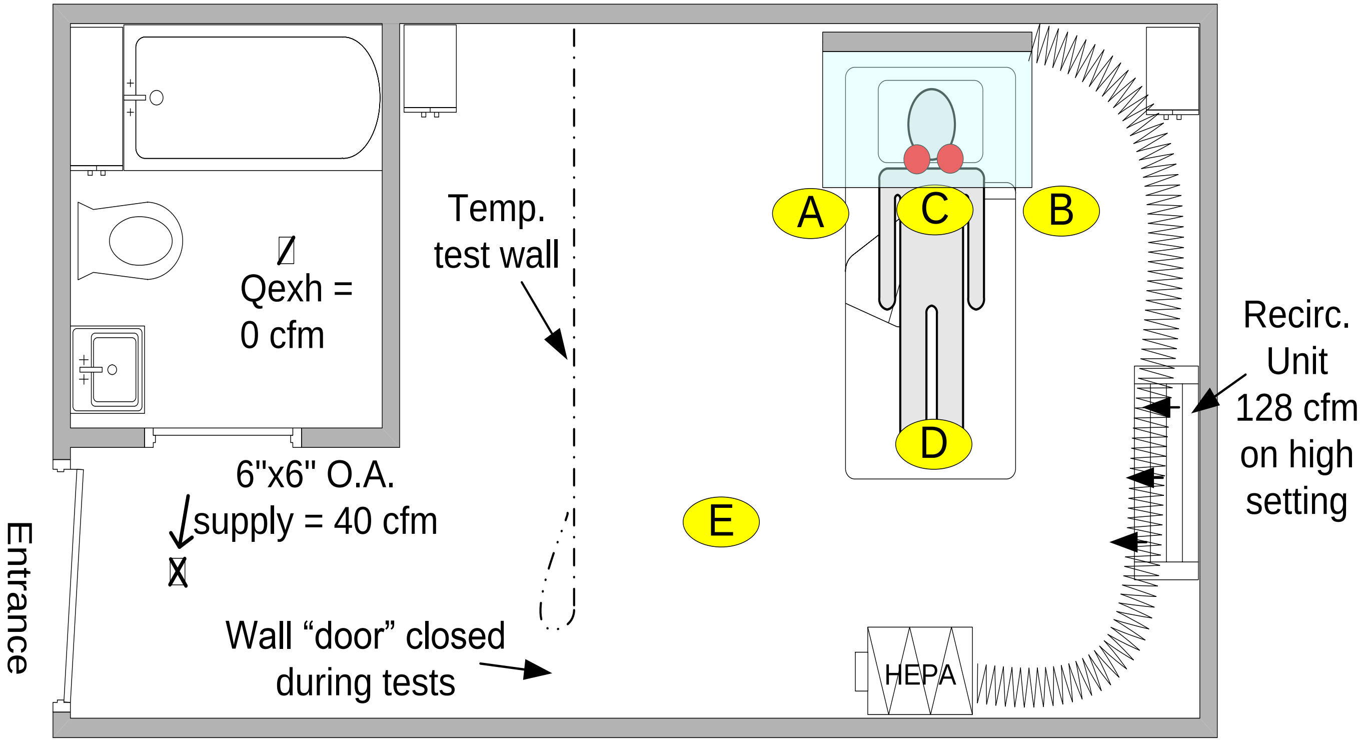


Sample locations (Grimm & IH)

Source generation points

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

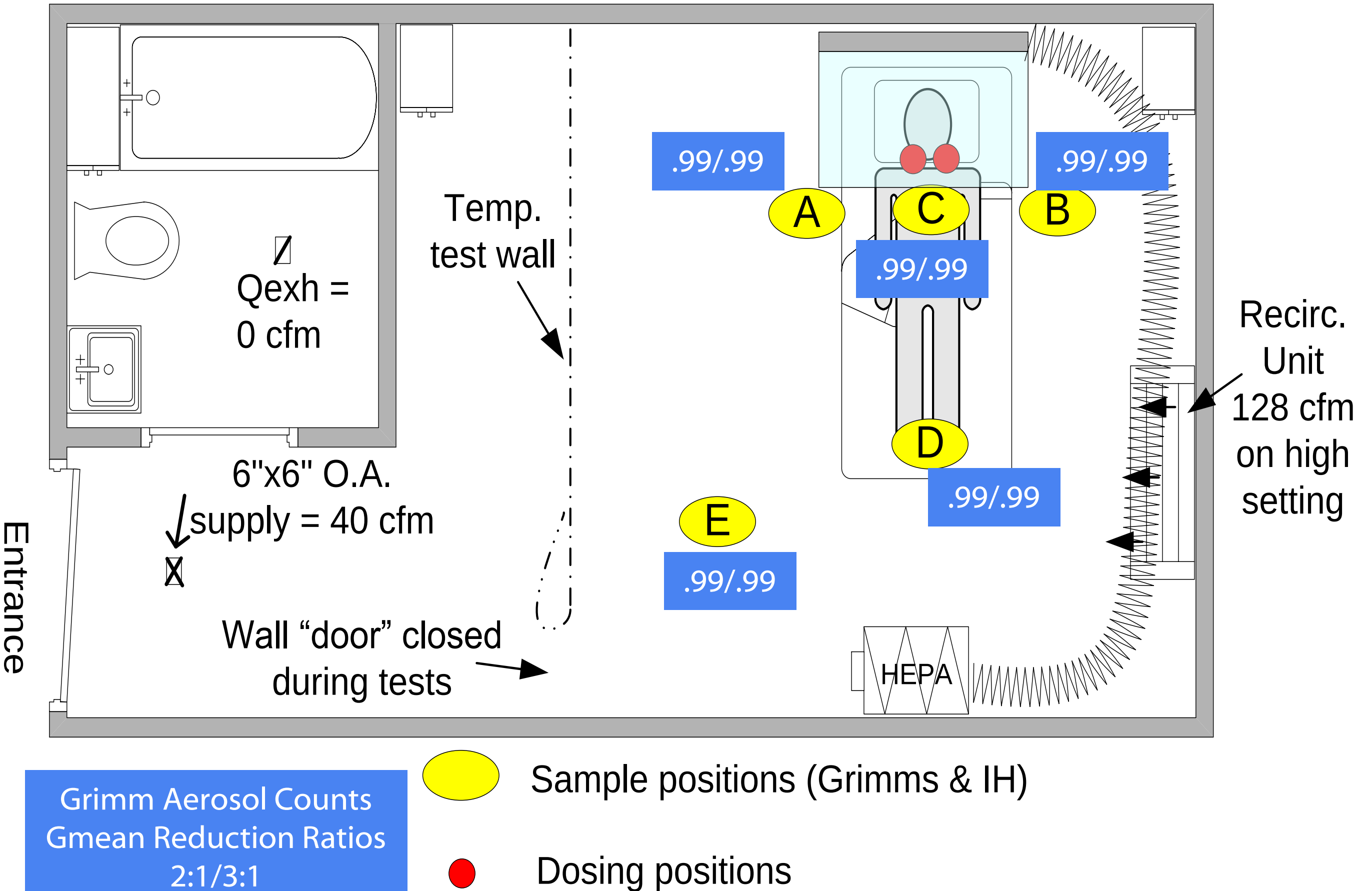
Ventilated Headboard (1-bed), ST Joseph Memorial Hospital (SJMH) Larned, KS



Sample positions (Grimms & IH)

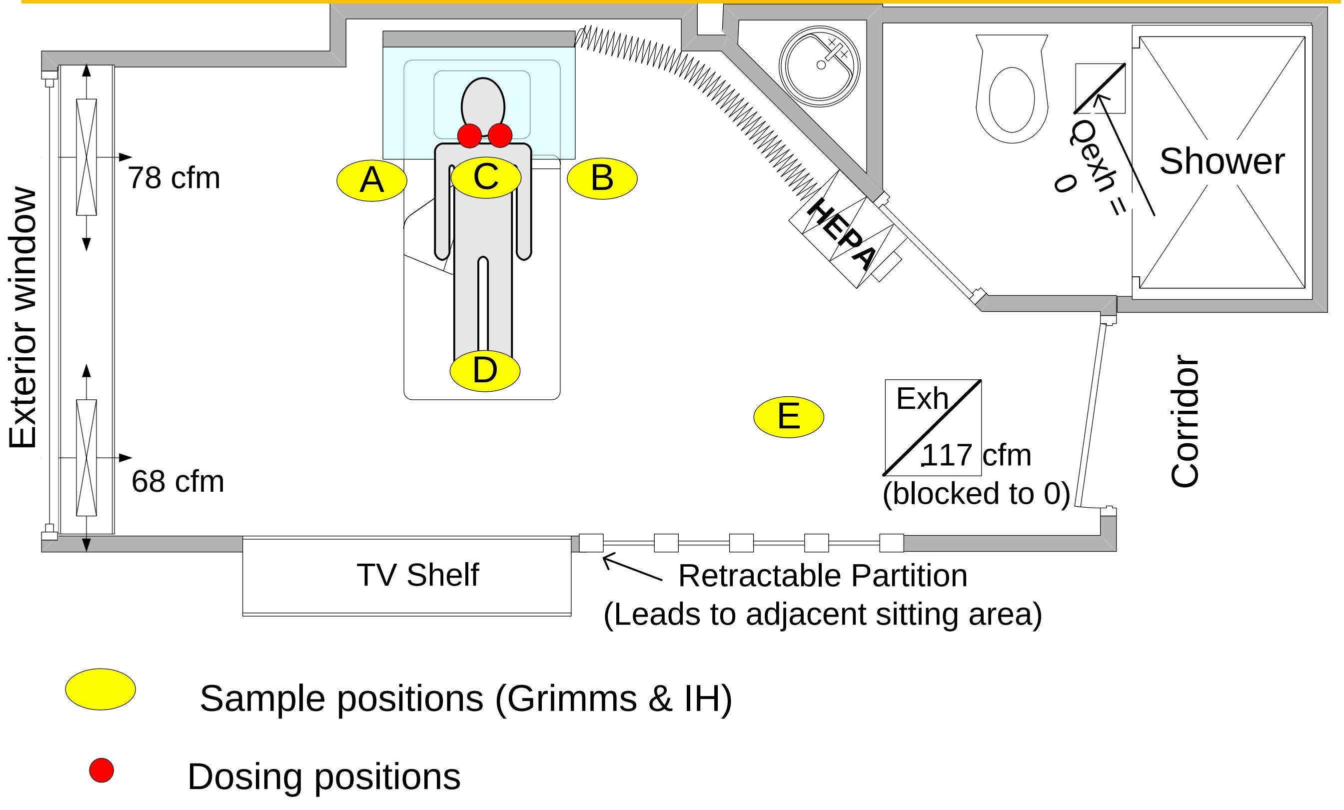
Dosing positions

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

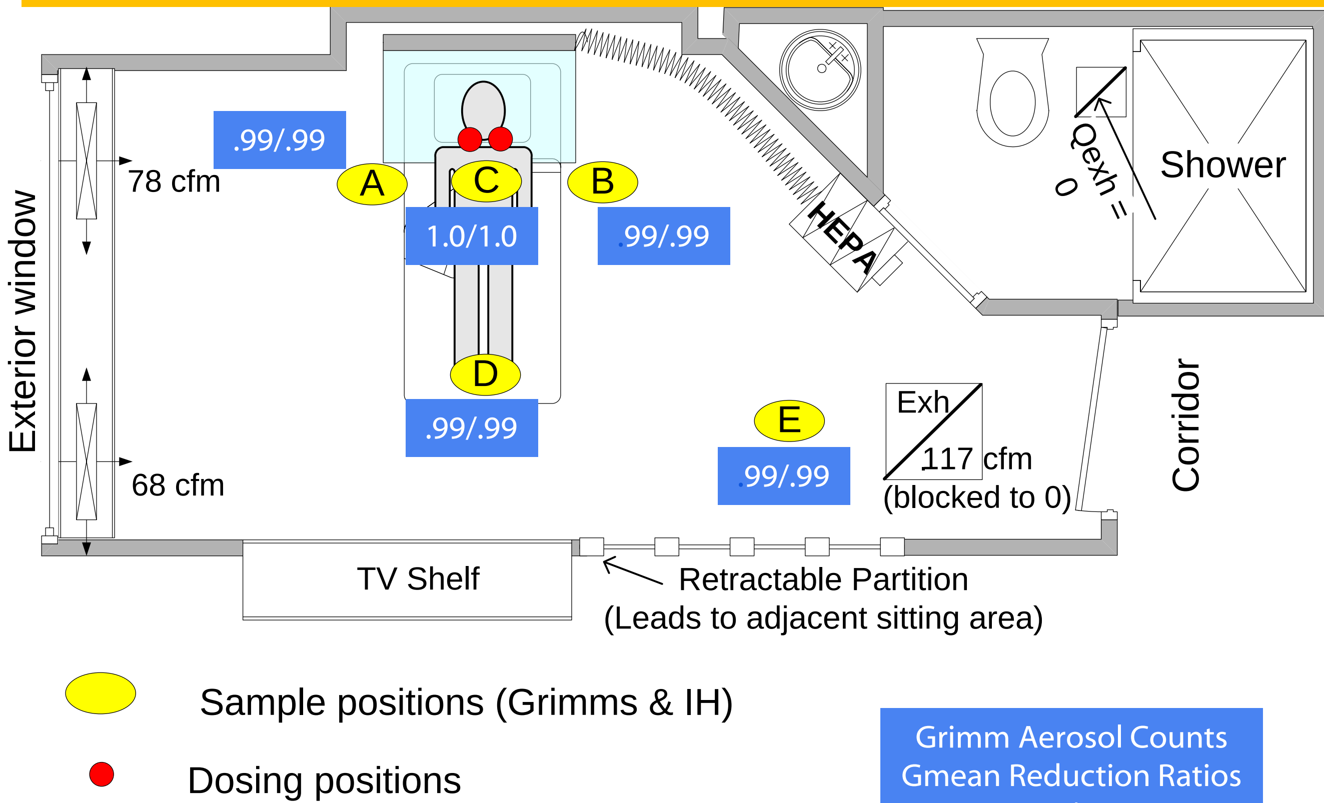


Grimm Aerosol Counts
Gmean Reduction Ratios
2:1/3:1

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



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



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

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%)

Hospital / *Sample Pos.*	*VAMC* 2:1	*VAMC* 3:1	*CKMC* 2:1	*CKMC* 3:1	*SJMH* 2:1	*SJMH* 3:1	*IBMC* 2:1	*IBMC* 3:1
HCW-RHS	0.987 (0.947	0.996 0.979)	0.999 (0.996	0.997 0.991)	0.998 (0.996	0.997 0.995)	0.998 (0.990	0.998 0.993)
HCW-LHS	0.997 (0.986	0.996 0.980)	0.998 (0.995	0.998 0.993)	0.998 (0.996	0.998 0.997)	0.999 (0.997	0.998 0.994)
Patient chest	1.00 (1.00	1.00 0.998)	0.967 (**0.898**	0.920 **0.724**)	0.998 (0.997	0.997 0.995)	1.00 (1.00	1.00 1.00)
Patient feet	0.995 (0.979	0.997 0.984)	0.996 (0.989	0.993 0.977)	0.996 (0.993	0.997 0.995)	0.998 (0.990	0.998 0.993)
Center Room	0.997 (0.988	0.996 0.980)	0.997 (0.990	0.996 0.985)	0.997 (0.995	0.998 0.996)	0.999 (0.994	0.997 0.989)

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:

$$EIPF = \left(1 - GMRR\right)^{-1.0}$$

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

Research Conclusion

(link to research report in your handout)

- 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 AII 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

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

Photo Credit: CDC/NIOSH

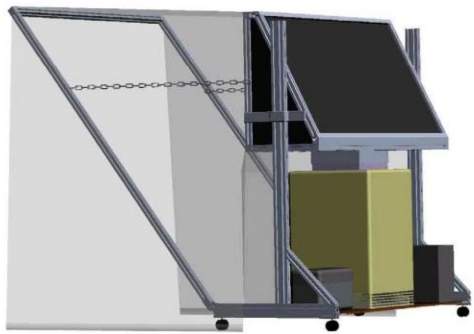
- “Wooden” prototype redesigned into DIY ($50) and extruded aluminum models.
- Light-weight, sturdy, easier to store/ship. Applicable to pre-planned emergency surge response kits.
- Height is adjustable to accommodate varying cot/bed heights.
- Coordinated with parts manufacturers to result in current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

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”



Image/Photo Credit: CDC/NIOSH

- 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)

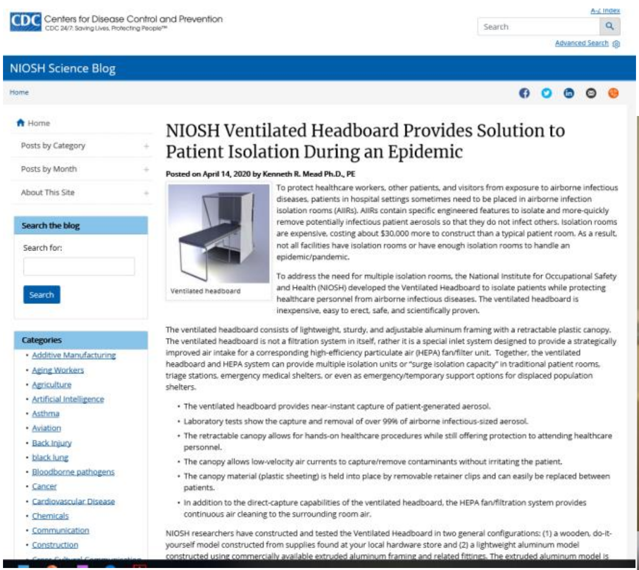
- Can be paired with solar/wind power sources for operation in austere environments without reliant power grid.

Alternative Application: Protective ("Reverse") Isolation

CDC/NIOSH Photo Showing Ventilated Headboard Tested In Reverse Isolation Mode:

- 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)

NIOSH Blog/Video



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NIOSH Ventilated Headboard Provides Solution to Patient Isolation During an Epidemic

Posted on April 14, 2020 by Kenneth R. Mead Ph.D., PE

Ventilated headboard

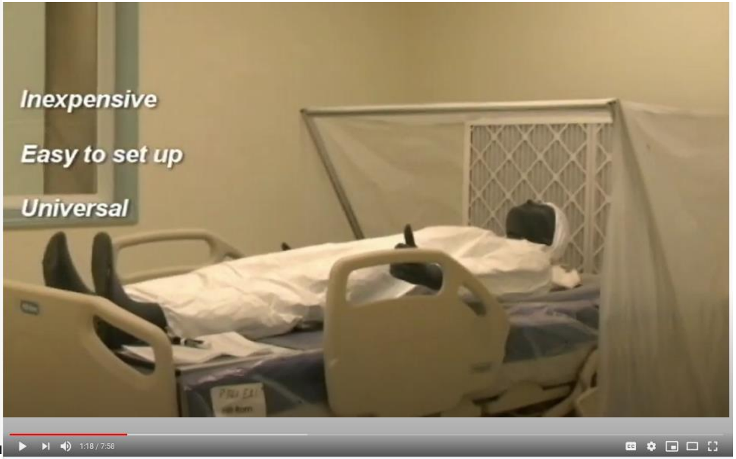
To protect healthcare workers, other patients, and visitors from exposure to airborne infectious diseases, patients in hospital settings sometimes need to be placed in airborne infection isolation rooms (AIIRs). AIIRs contain specific engineered features to isolate and more-quickly remove potentially infectious patient aerosols so that they do not infect others. Isolation rooms are expensive, costing about $30,000 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/pandemic.

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 intake for a corresponding high-efficiency particulate air (HEPA) fan/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 even as emergency/temporary support options for displaced population shelters.

- The ventilated headboard provides near-instant capture of patient-generated aerosol.
- Laboratory tests show the capture and removal of over 99% of airborne infectious-sized aerosol.
- The retractable canopy allows for hands-on healthcare procedures while still offering protection to attending healthcare personnel.
- The canopy allows low-velocity air currents to capture/remove contaminants without irritating the patient.
- The canopy material (plastic sheeting) is held into place by removable retainer clips and can easily be replaced between patients.
- In addition to the direct-capture capabilities of the ventilated headboard, the HEPA fan/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 constructed using commercially available extruded aluminum framing and related fittings. The extruded aluminum model is



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

Questions?

Contact info: Ken Mead (513) 841-4385
kmead@cdc.gov