Oklahoma State Department of Health Design and Implementation Guidelines for Airborne Infectious Isolation under Epidemic Emergency Response Conditions

Prepared by

David L. Johnson, PhD, PE, CIH
Department of Occupational and Environmental Health
College of Public Health
University of Oklahoma Health Sciences Center
P.O. Box 26901, Oklahoma City, Oklahoma 73190

August 31, 2005

Acknowledgments

This work was supported by the Oklahoma State Department of Health under the state's Health Resources and Services Administration (HRSA) Hospital Bioterrorism Preparedness Program grant. Special thanks are due to Kenneth Mead of the Division of Applied Research and Technology, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, for permission to use experimental data we jointly developed in pilot studies for his doctoral dissertation work at the University of Oklahoma College of Public Health. Thanks also to College of Public Health graduate research assistants Deepak Shinde and Sridhar Agraharam for their aid in the studies. Valuable medical insights and review comments on the drafts were provided by Timothy Cathey MD of the Oklahoma State Department of Health. The author is also deeply grateful to Harry Goett, Jim Trimberger, Ron Micue, and Brad Post of Integris Health of Oklahoma and Phil Comp, MD of the Oklahoma City Veterans Administration Medical Center for the generous loan of their facilities and equipment.

This document has not been reviewed and approved by HRSA or any other federal agency. The views expressed in this document are those of the author.

Table of Contents

Chapter I. Introduction and Background

I.A Purpose and Scope

Recent experience with Severe Acute Respiratory Syndrome (SARS) and the on-going threat of bioterrorism have heightened awareness of the need to be well prepared for a large-scale airborne infectious disease outbreak. Planning and associated infrastructure improvement to prepare for such events have been underway in the public health and health care communities for several years with funding support by the Health Resources and Services Administration (HRSA), Centers for Disease Control and Prevention (CDC), and other federal and state sources. However, challenges remain, including the challenge of developing surge capacity for isolating patients known or likely to be infectious by the airborne route. Isolation rooms must be specially engineered so that they can prevent the airborne pathogens from spreading to other hospital areas and to remove the pathogens from the air, but a 2002 survey by the Government Accounting Office revealed that two-thirds of over 1500 urban hospitals had 4 or fewer such isolation beds per 100 staffed beds (GAO, 2003). Although the number of isolation rooms has increased somewhat in recent years, it is still expected that a large-scale SARS or other airborne infectious disease outbreak would rapidly saturate the available capacity. It is therefore necessary to make surge preparedness plans for airborne infectious isolation under epidemic emergency response conditions.

The purpose of this document is to: (1) review current airborne infectious isolation guidelines for normal health care operations, (2) summarize the ventilation design principles and experience upon which the guidelines are based, (3) discuss approaches to developing isolation surge capacity designs that meet isolation goals to the extent possible with the resources available, (4) provide data-based recommendations for expedient isolation system designs, and (5) identify commercial sources for useful components and systems. The material is neither definitive nor prescriptive – rather it is intended to assist preparedness planners by stimulating their thinking and facilitating design, development, and preparation of isolation surge capacity systems.

I.B Airborne Disease Transmission in Health Care Environments

A number of viruses and bacteria have been associated with human-to-human airborne disease transmission in health care environments. Of the bacteria, *Mycobacterium tuberculosis* is of greatest concern and the CDC has special infection control guidelines in place for health care facilities (CDC, 1994; CDC, 2005) as well as correctional institutions and other high risk environments. Of the viruses, the SARS-associated coronavirus (SARS-CoV) responsible for the 2004 outbreak in China and Canada and the H5N1 avian influenza virus producing human fatalities in China and Southeast Asia beginning in 2004 are

currently of great concern because of their likely recurrence and relatively high mortality. H5N1 has not been shown to have a high potential for human-to-human spread, but this could change as the virus continues to evolve. Although isolation may be of limited usefulness in preventing the spread of influenza during a large-scale outbreak due to the short incubation period (2-4 days) and virus shedding by asymptomatic persons (about half of those infected) (NJDHSS, 2004), isolation may be more effective in limiting SARS transmission. Isolation would also be essential for preventing Smallpox transmission in the event of a bioterrorist attack using this agent (English et al., 1999; CDC, 2002).

As discussed by Garner and HICPAC (1996), although disease transmission can occur via exposure to droplets aerosolized by patients during talking, sneezing, or coughing or by certain procedures that can aerosolize the patient's oral and nasal secretions, this transmission is primarily by droplet contact with the conjunctiva, nasal mucosa, or mouth of the exposed person rather than by inhalation. These droplets are greater than 5 micrometers (μm) in size, do not remain airborne long or travel very far, and are primarily a hazard to persons within a distance of about three feet. However, these droplets are largely water, and the water may evaporate to leave much smaller pathogen-containing particles in the 1-5 μm size range that can remain airborne for much longer periods and travel with air currents to areas far from the source. Tuberculosis and Smallpox have both been shown to travel long distances in droplet nuclei and produce infection when subsequently inhaled; there is less evidence to indicate whether SARS can be transmitted by droplet nuclei. Because droplet nuclei will move with the air, isolation and ventilation systems are designed to contain the air around an infectious patient to prevent it from escaping to other areas, and to remove the droplet nuclei from the air to minimize the airborne concentration to which care providers entering the space may be exposed.

Chapter II. Engineered Airborne Infectious Isolation Rooms

II.A Airborne Infectious Isolation Room Standards and Guidelines

Several sources of design recommendations for Airborne Infectious Isolation Rooms (AIIR) in health care facilities are available in the US and internationally. In the US the American Institute of Architects (AIA) *Guidelines for Design and Construction of Hospital and Health Care Facilities* (AIA, 2001) has been accepted by regulatory and accrediting agencies and the medical community as the primary standard governing AIIR design for US facilities (CDC/HICPAC, 2003). Guidance by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides more detailed recommendations on ventilation system design and performance goals (ASHRAE, 2003). Guidance on the use of ventilation and ultraviolet germicidal irradiation (UVGI) for control of *Mycobacterium tuberculosis* is provided by the Centers for Disease Control and Prevention (CDC) (CDC, 1994). The CDC and its Healthcare Infection Control Practices Advisory Committee (HICPAC) recently published more general and updated guidance on environmental infection control in health care facilities that incorporates portions of these other guidelines (CDC/HICPAC, 2003). In addition, useful recommendations may also be drawn from international sources as shown below. The primary recommendations from each of these are discussed in the following sections.

II.A.1 AIA Guidelines

AIIR design requirements are found in § 7.2.C of the AIA *Guidelines*, and include:

- An area immediately outside or inside the entry door of the AIIR for handwashing, gowning, clean items storage, and soiled storage. An exhaust-ventilated alcove or anteroom between the AIIR and the adjacent space is recommended for this purpose.
- Well-sealed wall-floor, wall-wall, and wall-ceiling joints and other penetrations to prevent air flow between the AIIR and surrounding spaces.
- Self-closing doors.
- Dedicated toilet, bathing, and handwashing facilities for each AIIR.
- Continuously operating air flow direction monitors. In practice these are usually manometers (pressure differential meters) that activate audible and/or visual indicators when the AIIR pressure is not sufficiently negative compared to the surrounding area.

AIIR ventilation requirements, when patients are present, are found in Table 2 of the *Guidelines*:

- An exhaust rate of at least 12 air changes per hour (ACH) in the AIIR. An air change is one room volume of air, so 12 ACH is equivalent to an exhaust ventilation rate of 12 room volumes of air per hour. For a 1500 cubic foot (ft^3) room this would be 18,000 ft^3 per hour or 300 ft^3 per minute (cfm).
- Of the 12 ACH, at least 2 ACH should be fresh air brought in from the outdoors.
- Air flow should be into the space from the adjacent area. This will occur when the room air pressure is slightly lower than that of the adjacent space, i.e. the room is “negative” relative to the adjacent space. A minimum pressure differential of .01 inches water gauge (2.5 Pascals) is required.
- All air should be exhausted directly to the outdoors, except that HEPA-filtered air may be returned to the AIIR if the AIIR is served by a dedicated HVAC unit (that is, not other areas are served by that HVAC unit).
- Recirculating HEPA filtration units may be used inside an AIIR to increase the removal of airborne infectious agents, and their flowrate may offset part of the 12 ACH ventilation requirement. However, the 2 ACH fresh air supply requirement must still be met.
- When an alcove or anteroom is used, it should be exhausted at a rate of at least 10 ACH.

*Note that "Protective Environment Rooms" are not the same as Airborne Infectious Isolation Rooms***.** Protective Environment rooms are designed to maintain a *positive* pressure relative to surrounding areas to prevent immunosuppressed and other infection-susceptible patients from being exposed to airborne infectious agents. These rooms should not be confused with AIIR. In past years, "dual-use" rooms with reversible HVAC systems were in place in some facilities; due to the significant risk of operating the HVAC in the wrong mode, these systems are no longer acceptable.

The AIA guidelines specify that at least one AIIR should be provided in the Medical/Surgical Nursing Units, Critical Care Unit, Pediatric Critical Care Unit, Pediatric and Adolescent Unit, and the Emergency Service (§ 7.2.C, 7.3.A14, 7.3.D, 7.5.C6, 7.9.D5). The guidelines further specify that additional AIIR may be required in these areas as well as Diagnostic Imaging waiting, Outpatient Clinic, and Obstetric Clinic areas if so determined through an Infection Control Risk Assessment (ICRA). ICRAs are conducted by a panel of persons "with expertise in infection control, risk management, facility design, construction, ventilation, safety, and epidemiology" (§ 5.1).

II.A.2 ASHRAE Guidelines

The ASHRAE AIIR ventilation requirements (ASHRAE, 2004, § 12.3.4) are the same as those of the AIA described above. In addition, though, they specify that supply air filters should be at least 90 percent efficient by the dust spot test

(§ A.5). The dust spot test is the appropriate indicator of a filter's ability to capture extremely fine particles such as droplet nuclei. The weight arrestance test, which is often used to describe HVAC filter efficiency and is appropriate only for particles much larger than droplet nuclei, gives a misleadingly high rating of filter efficiency. ASHRAE further states that the pressure differential between the patient care area and the adjacent area should be between .01 and .03 inches of water gauge (2.5 to 7.5 Pascals) (§ A.5.2).

The ASHRAE guidelines discuss the importance of establishing an airflow arrangement that will minimize exposure of health care workers and others in the space. Essentially this refers to the need to encourage air mixing in the space in order to maximize dilution ventilation efficiency (dilution ventilation is discussed in section III.B.1 below). Health care providers are protected to the extent that the dilution ventilation is able to maintain the airborne infectious agent concentration at low levels in spite of the ongoing airborne droplet nuclei generation by the patient.

The ASHRAE guidelines recommend standard Type A ceiling-mounted horizontal-throw supply air diffusers placed in the center of the ceiling or slightly toward the entrance. The horizontal throw should be capable of reaching the walls, but care should be taken to avoid creating high-velocity air currents in the vicinity of the doorway. Ceiling-mounted exhaust registers should also be used, and the exhaust register should be placed directly above the patient bed, at the head end if possible, to promote a degree of directional airflow and thereby move droplet nuclei away from health care providers. Exhaust grilles must be kept clean to avoid clogging with lint and dust, which can reduce exhaust flow rates and cause the room to be under less negative pressure than is required.

Internal heat gains in the AIIR due to the patient, care providers, equipment, solar load (if there are windows), and heat conduction through the walls will generally require that an AIIR be cooled rather than heated (though this may not be the case during cold weather if the AIIR is on an outside wall). However, typical heat gains can be easily handled by ventilation at the recommended 12 ACH or 145 L/s rate with 55 F temperature supply air (ASHRAE, 2004, § 12.3.4).

II.A.3 Centers for Disease Control and Prevention Guidelines

CDC/HICPAC AIIR design requirements are also quite similar to the AIA and ASHRAE requirements. Additional guidance includes:

- AIIR constructed before the 2003 guideline date may have a minimum 6 ACH ventilation rate, but renovated or new AIIR should have at least 12 ACH.
- Anterooms are not required, but if used for infectious patients who are not also immunocompromised they should be under positive pressure relative to both the patient area and the surrounding area, with air moving out of

the anteroom at both doorways. This will require that the anteroom have its own air supply.

II.A.4 International Guidelines

Northern Ireland (RACCDC, 2004) and Australia's State of Victoria (DHSSCIC, 1999) have published AIIR guidelines that are in some cases more specific or more stringent than the US standards:

- A minimum pressure differential of 15 Pascals for AIIR, compared to 2.5 Pascals in the US.
- Ventilation should be at a rate of at least 12 ACH or 145 liters per second (307 cfm) per patient, whichever is higher. The per-patient criterion has the effect of limiting the steady state contaminant concentration that might result in small single-patient rooms or in multi-patient rooms (Marshall, 1996) (see also the discussion of dilution ventilation in section III.B.1 below).
- An anteroom should be used, and should have a minimum floor area of 7 square meters (m^2) or 75 ft^2.

II.B Operation and Maintenance of AIIR Ventilation Systems

The critical challenge in operating an AIIR ventilation system is to maintain the AIIR under a negative pressure differential of at least .01 inches water gauge (2.5 Pascals) relative to adjacent areas, so that air flows occur in the right direction. The pressure differential is determined by the difference between the exhaust flow rate and the supply flow rate; the exhaust flow rate must be enough greater than the supply rate that the required negative pressure is developed. In a well-sealed AIIR a flow difference of at least 125 cfm may be sufficient (Streifel, 2000), though flows as low as 75-100 cfm through one door to an AIIR have been shown to work as well (Gill, 1994). Although the proper balance may be achieved when the system is new, air flow rates may change over time. Factors that can cause a change include:

- Dirty Filters. Dirty exhaust pre-filters or HEPA filters cause increased flow resistance and lower exhaust air flow rate. Filter housings should be fitted with pressure drop indicators (manometers) that allow daily checks of the filters' condition, so that filters can be changed before becoming too dirty.
- Dirty Exhaust Grille. Accumulation of lint and dust on the room's exhaust grille can cause increased resistance to air flow through the grille, decreasing the exhaust air flow rate. Exhaust grilles should be regularly cleaned.
- Mechanical Wear. Mechanical components such as fan bearings and fan belts can wear over time, causing lower fan speeds and subsequently

lower exhaust air flow rates. Regular preventive maintenance should be performed, including measuring fan rotation rates.

- Leakage. Damage to seals around windows, doors, and other penetrations can allow leakage into the AIIR, thereby reducing the effective supply-exhaust flow differential and the pressure differential. Seals should be inspected regularly to make sure they are intact. Qualitative leak tests with "smoke" tubes may be used to follow air currents and check for leakage points. Pressure differential measurements using a sensitive digital micromanometer will indicate unseen leaks.
- Change in System Components. Well-meaning maintenance personnel may substitute lower-cost filters for those intended to be used with the supply and exhaust systems. If a lower-resistance supply filter is substituted, the supply air flow rate may be too high. If a higher-resistance exhaust pre-filter is substituted, the exhaust flow rate can fall. In both cases the flow and pressure differentials are reduced. Only the filter types specified by the system designer should be used.

Standard procedures should be developed for AIIR inspection and maintenance, and a detailed record should be kept of all performance checks and maintenance that are performed.

Chapter III. Airborne Infectious Isolation Units for Surge Capacity

III.A Airborne Infectious Isolation Units

In the event of a severe infectious disease outbreak such as SARS it might be expected that the limited AIIR capacity of a health care facility would be saturated. This would require placing infectious patients in non-AIIR treatment areas if they could not be transferred to other facilities. In its guidance on community-level preparedness and response to SARS, the CDC recommends that health care facilities develop institutional preparedness and response plans that include plans to "rapidly implement effective infection control measures" and to determine the "availability of infrastructure and resources to care for SARS patients and strategies for meeting increasing demands" (CDC, 2004). Certainly this includes plans to establish surge isolation capacity in treatment areas. These would be termed Airborne Infectious Isolation Units (AIIU). As described by the New York State Department of Health, an AIIU is an area that is used for airborne infectious patient isolation in an emergency, but that is not normally used for that purpose (NYSDOH, 2003). That is, the space was not designed and constructed to be an AIIR, but with appropriate modifications has been made to functionally approximate an AIIR.

In developing plans and designs for AIIU the intent should be to achieve isolation goals, i.e. to contain the contaminant and apply engineering measures to reduce its concentration *to the extent possible with the resources available*. This will require some creative thinking by a group of individuals such as those who might normally make up an ICRA panel: individuals with expertise in infection control, epidemiology, patient care, risk management, safety, and facility design, construction, and ventilation. Those with expertise in bioterrorism preparedness and response would also be important members of this group. An understanding of basic ventilation concepts and how they apply to airborne infectious agent control is needed to inform AIIU design and develop appropriate work practice and personal protection precautions. These concepts are reviewed in the following sections.

III.B Heating, Ventilating, and Air Conditioning (HVAC) Concepts

HVAC systems maintain comfortable temperature and relative humidity in a space by circulating the air through an air handling unit (AHU) that filters the air, heats or cools it, and perhaps adjusts its moisture level, before returning all or most of the air to the conditioned space. Large-building commercial HVAC systems normally recirculate at least 90 percent of air exhausted from a conditioned space to reduce the system's heating/cooling demand and minimize energy costs. Because indoor air pollutants can build up over time and cause indoor air quality problems if 100 percent of the air is recirculated, HVAC designers often provide for some minimum fraction of the exhausted air to be

dumped to the outdoors and an equal volume of fresh air to be drawn in from outdoors and conditioned by filtration, humidification/dehumidification, and heating/cooling to maintain comfortable temperature and humidity. Although the system is designed with some consideration of contaminant control, the main consideration is to maintain temperature and humidity within a comfortable range. ASHRAE guidelines preclude recirculation to many areas of hospitals and clinics but allow it in other areas such as examination, treatment, labor and delivery, and patient rooms that might be utilized as AIIU (ASHRAE, 2003, Table 2).

During moderate weather the amount of fresh air may be increased to take advantage of the outdoor air temperature for energy conservation; the increased outdoor air will also improve indoor air quality provided no contaminants are inadvertently brought in from the outdoors, such as engine exhausts or odors. Large-building HVAC systems will often have an Energy Management System that monitors indoor and outdoor conditions and adjusts the fresh air fraction automatically, or that is set to change the fraction at pre-set times and dates based on building occupancy patterns and seasonal temperature conditions (ASHRAE, 2003, Chapter 10).

HVAC ventilation for comfort control is different from AIIR/AIIU ventilation, which is intended primarily to contain contaminants (droplet nuclei) and subsequently remove them from the space. As described in Chapter II, AIIR/AIIU ventilation systems are usually 100 percent exhausted to the outdoors, i.e. they are “single pass” systems in which air passes through the space only one time. The exception is for a system that serves only the AIIR space and HEPA-filters the air before returning it to the AIIR. While AIIR are designed to be independent of the building’s HVAC systems or to operate in concert with the building HVAC, AIIU designs must be developed to contain droplet nuclei and minimize their concentration *in spite of* the building’s normal HVAC operation. This requires an understanding of both HVAC and exhaust ventilation principles.

III.B.1 Exhaust (Dilution) Ventilation

Exhaust ventilation removes contaminated air from a space and replaces it with clean air in order to reduce the concentration of airborne contaminants. An exhaust fan draws air out of the room at an exhaust grille or grating and through a ventilation duct so that the air can either be cleaned for return to the space or dumped to the outdoors. In the case of infectious droplet nuclei the air may be disinfected by HEPA filtration, perhaps with supplemental ultraviolet germicidal irradiation (UVGI), and returned to an AIIR if the ventilation system serves only that space. In that case the air may be HEPA-filtered and the bulk recirculated (though not all, since at least 2 ACH of fresh air must be provided and therefore at least 2 ACH of the exhausted air must be dumped). Air that cannot be returned to an AIIR should also be HEPA-filtered before being dumped to the outdoors to avoid exposing anyone present outdoors or drawing infectious agent back into

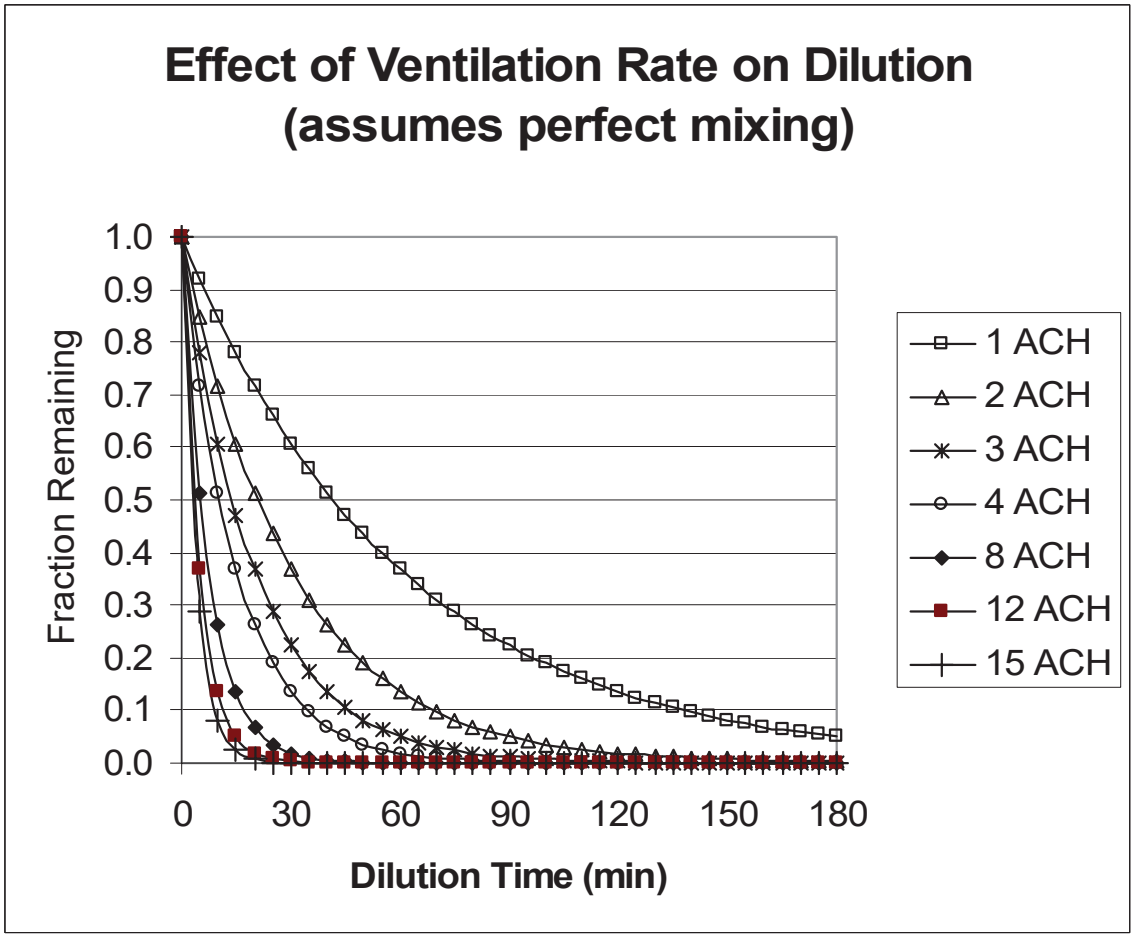
the building through air intakes, open windows and doors, or leakage points in the building structure.

When contaminated air is exhausted from a space an equal volume of “makeup” air must enter the space, either through the supply air diffuser or via open doors and windows, cracks around closed doors and windows, or other leakage points. This clean air mixes with the contaminated air in the space to dilute the contaminant concentration. If no additional contaminant is added after exhaust begins, the concentration will decrease over time until the contaminant is completely removed. A *constant fraction* of the remaining contaminant is removed with each minute the exhaust operates, so that over time the *amount* of contaminant removed each minute decreases. For example, if half of the original concentration is gone after one hour, then three-fourths will be gone after two hours, seven-eighths after three hours, and so on. That is, for each hour of operation the concentration would be halved again, so that under these conditions the contaminant would have a 1-hour “half-life” in the space. For a given situation, the half-life will depend on the space volume (ft^3), the clean air ventilation rate (cfm or ACH), and the amount of mixing in the room. The half-life shortens with increasing clean air ventilation rate and degree of mixing and lengthens with room volume. For a given room the half-life can be shortened by increasing the clean air ventilation rate and/or improving the mixing. This "exponential decay" in the concentration is shown graphically in Figure 1. The figure shows the dramatic difference in how quickly the concentration drops off at high clean air ventilation rates compared to low ventilation rates.

Figure 1 is provided to demonstrate the dependence of contaminant clearance rate on the amount of clean air ventilation in ACH. However, in a patient care environment the generation of infectious airborne droplet nuclei goes on at the same time the ventilation system is trying to remove particles from the room. If both the ventilation rate and droplet nuclei generation rate are constant, a steady contaminant concentration will develop in the room over time that is the ratio of the generation rate and the clean air ventilation (removal) rate. As an illustration, imagine that a patient generates 1 infectious particle per second on average and the room is ventilated at 100 cfm of infectious-particle-free air with perfect mixing. Then the "equilibrium concentration" of infectious particles would be 60 particles per min ÷ 100 ft^3 per min = .6 particles per ft^3 or about 20 particles per m^3. If the clean air ventilation rate is doubled, the equilibrium concentration is halved to about 10 particles per m^3. Thus, the amount of clean air ventilation provided by the ventilation system should be sufficient not only to maintain adequate negative pressure and contaminant containment, but also to maintain the contaminant concentration at the lowest level that can be reasonably achieved. Note that for a clean air ventilation rate of say 12 ACH, the equilibrium concentration produced at a given droplet nuclei generation rate will depend on the room volume – it will be lower for large rooms than for small rooms if both rooms are equally well mixed. The 145 liters per second per patient ventilation rate recommended in Australia and Northern Ireland would place an upper limit on the equilibrium concentration for very small rooms (see DHSSCIC,

1999, § 5.5). Although this standard is not required in the US for AIIR, it should be considered for application in both AIIR and AIIU.

Figure 1. Exponential Contaminant Concentration Decay Over Time for Various Fresh Air Ventilation Rates



III.B.2 Directed Air Flow Ventilation

Directed air flow ventilation differs from dilution ventilation in that the air is caused to move in only one direction rather than mixing in the room. Laminar flow surgical suites in which the air moves from ceiling supply vents directly toward floor exhausts are an example of directed air flow ventilation. This type of unidirectional air flow is not really achievable in an AIIR, and ASHRAE recommends that it not be attempted (ASHRAE, 2003). However, quasi-directional airflow in the vicinity of the patient can be attained under certain conditions, as previously discussed regarding exhaust grille placement above the patient bed (see section II.A.2 above). Recent AIIU research has also

demonstrated that directional airflow can be achieved in single-patient partial and complete AIIU enclosures if properly designed (Mead and Johnson, 2004). However, this required a different design approach than is permitted for AIIR but which may be necessary for AIIU, especially under high surge conditions. These will be discussed in the following sections.

III.C AIIU Design

AIIU design requires creative thinking by a team of individuals with expertise in infection control, epidemiology, patient care, risk management, safety, and facility design, construction, and ventilation. There is no cookbook method for AIIU design, which in the end is performance driven – either the AIIU works satisfactorily or it doesn't. There may be several ways to achieve the end result of infectious droplet nuclei containment and removal, and individual professional judgment informed by general design guidelines is likely to produce the most appropriate designs for a given facility and scenario.

III.C.1 Critical and Desirable AIIU Characteristics

Critical features of a candidate AIIU might include:

- Will provide, when properly configured, a negative pressure environment capable of containing and removing infectious droplet nuclei and providing the required clean air ventilation rate
- Is suitable for the intended patient care
- Provides an ability to control access to the space and movement through it
- Can be suitably air conditioned to maintain comfort

Additional desirable but perhaps non-critical characteristics might include:

- Provides single-patient isolation
- Can be exhausted to the outdoors
- Can be quickly converted from its usual use to AIIU use by minimally trained personnel
- Does not require expensive, dedicated equipment for the conversion

III.C.2 Surge Response Planning and Preparation

Planning and preparation for response to a surge isolation demand could involve a process such as (adapted from NYCDOH, 2003 and CDC, 2004, Supplement C: Preparedness and Response in Healthcare Facilities):

- Scenario development
    - Project potential levels of surge demand associated with various scenarios, e.g. SARS outbreak, Smallpox bioterrorism event
    - Stratify the demand
        - Minimal surge – can respond primarily with existing AIIR capacity, though some services may be affected; some AIIU may be needed
        - Moderate surge – can respond with AIIR supplemented with AIIU capacity within the facility, but with potentially severe disruption of other services
        - High surge – available AIIR and AIIU capacity will be saturated; patients may be redirected/relocated to dedicated facilities away from the hospital
- Establish the limits of acceptable performance
    - Realize that AIIU performance will likely not be equivalent to AIIR performance for all AIIU in the facility
    - Decide upon the limits of acceptable performance, i.e. the "must have" vs. the "like to have" performance criteria – e.g. single-patient AIIU are desirable but may not be practical in certain facilities or surge situations, and though a 70-75 F temperature range is desirable that also may not be achievable as AIIU affect the HVAC system's performance; droplet nuclei containment, however, should be considered a "must have"
- Facility survey and systems documentation
    - Inventory existing AIIR and verify their performance
    - Document the operation of building HVAC systems
    - Identify potential sites outside the facility that could serve as dedicated isolation facilities and document their systems as well
- Identify areas that have AIIU potential
    - Can be separated from other areas with physical barriers
    - Can be maintained under negative pressure relative to surrounding areas
    - Have dedicated handwashing, bath and toilet facilities
    - Are served by conditioned HVAC supply air but can be isolated from the building's HVAC return-air system to avoid droplet nuclei spread
    - Can be exhausted to the outdoors
    - Preferably can provide single-patient isolation

- AIIU design
    - Focus on the primary goals: contain the droplet nuclei and reduce their concentration to minimize provider exposure risk
    - Design around the facility characteristics – the design should take advantage of each AIIU area's HVAC and physical features
    - Work from the simple to the more complex - use the simplest design capable of achieving the isolation goals
- AIIU implementation and performance evaluation
    - Secure the materials and equipment needed to convert a candidate area to an AIIU
    - Perform a test implementation of the design and verify its performance by qualitative and quantitative testing (see Chapter IV below)
    - Modify the initial design based on the performance evaluation data and re-evaluate
- Functional evaluation via drills and exercises
    - Identify individuals who would be responsible for AIIU set-up during a surge response
    - Train these individuals regarding the why and how of setting up and evaluating their AIIU
    - Drill them in setting up the AIIU and verifying its performance, and retrain as necessary
    - Conduct exercises to simulate patient care in the AIIU and identify design modifications or work practice changes required to achieve the isolation goals; such exercises are also important to reinforce provider training in infection precautions and to evaluate an AIIU's ability to maintain comfort conditions (temperature and humidity) under load

III.C.3 Some AIIU Design Considerations

Several design considerations have already been noted. Candidate AIIU areas should be chosen that can be physically separated with barriers that both isolate the patient care area and restrict access and traffic flow, and it must be possible to prevent droplet nuclei from spreading to other areas. The achieve the latter it must be possible to keep the AIIU under slight negative pressure relative to the surrounding areas, and to prevent the droplet nuclei from moving to other areas through the HVAC system. A facility will likely have a number of HVAC units, each serving a defined space or "zone", and these zones provide a basis for selecting AIIU areas. Negative pressure results when the amount of exhausted air exceeds the amount of supply air, provided the AIIU is well sealed to minimize leaks, so AIIU areas comprising an HVAC zone offer the greatest ability to physically separate the area from adjacent areas and to regulate exhaust ventilation or air supply rates. Zones served by individual HVAC units

can be readily identified from the mechanical system drawings (blueprints) for the facility, which will be on hand in the facility engineering office. Some familiarization with drawing conventions and symbols is needed, but many "How to Read HVAC Blueprints" references designed for non-engineers are available, or the facilities engineering staff can provide explanations. The major point is that the design team must have a thorough understanding of the building's HVAC systems and the effect any changes (such as erecting barriers or blocking HVAC supply or exhaust vents) might have on their operation, including maintenance of pressure balances throughout the facility. Knowledgeable facility engineering personnel are key to the planning process, and should be intimately involved in the development and evaluation of candidate AIIU designs.

III.C.4 Supplemental HEPA Filtration

It probably will not be possible to provide 12 ACH of ventilation including at least 2 ACH of fresh air in all AIIU, so that supplemental recirculating HEPA filtration units will be highly useful. As shown in Appendix B, a number of vendors provide both fixed (wall- or ceiling-mounted) and free-standing fan/filter units that draw air through a HEPA filter and return it to the space. Properly operating HEPA filters remove 99.97 percent of 0.3-μm airborne particles, which are the most difficult to filter out, and even higher percentages of both smaller and larger particles. From an infectious droplet nuclei perspective they are essentially absolute filters that remove all such particles from the air. Case Study A.1 in Appendix A illustrates how a recirculating HEPA unit with an appropriately high flow rate can rapidly reduce particle concentration in a space. The rate of particle removal depends on the HEPA flow rate, so it is important to have a high flow rate relative to the space volume. For example, a moderate-size HEPA unit providing 350-cfm flow rate in a 1750-ft^3 space provides the equivalent filtration rate of 0.2 air changes per minute or 12 ACH. An additional benefit of recirculating HEPA filtration to remove infectious droplet nuclei is that the unit will also remove other particles that may cause patient discomfort or pose an infection or allergy risk, such as pollens, mold spores including infectious *Aspergillus* spores, and particles containing latex proteins generated during donning and removal of both powdered and "powder-free" latex gloves (Phillips et al., 2001). The HEPA units thereby improve overall *particulate* air quality in the space.

Maintenance is required to maintain HEPA performance. The units typically have paper (not spun fiberglass) pre-filters designed to retain larger particles that can clog the HEPA filter prematurely, and these must be regularly changed to both protect the HEPA filter and to prevent the filters from building up too much resistance and restricting the unit's flow rate. The change schedule will depend on how much the units are used and how much dust is in the air. However, according to manufacturers, large units providing several hundred cfm of flow rate will require a HEPA filter change and recertification only every one to two years in typical indoor environments even if used continuously.

A note regarding gases and vapors: HEPAs are particle filters, and do not remove gases or volatile organic chemical vapors unless they are equipped with appropriate sorbers employing activated carbon, silica gel, or special sorption media. Units can be purchased with sorption components, but users should be aware that the sorbers become saturated over time and must be replaced on a fairly regular basis. The manufacturer should be consulted to determine the appropriate replacement schedule.

III.D Expedient Isolation for Unanticipated or Extreme Surge Events

A high surge event has a low probability of occurring, but if it *should* occur it could very well require a maximum AIIU response that exceeds the facility's planning and preparation level. The facility may be faced with expanding its AIIU capability beyond that for which is has prepared or to areas not particularly well suited to AIIU use. Rapid response to provide additional AIIU capacity will require simple construction using on-hand or readily obtainable equipment and materials. The following sections offer some strategies for such a response.

III.D.1 Hospital Care Areas

Hospital emergency departments (ED) will likely have only one engineered AIIR for patient isolation. Patients arriving in the ED who are known or believed likely to be infectious should be immediately isolated from other patients, visitors, and the ED staff. If a negative pressure AIIU cannot be quickly established, several approaches might be considered. The simplest would be to place the patient inside a closed room with a HEPA filter unit as described in Case Study A.1 of Appendix A. If the patient is placed in a bed, a ventilated headboard as described in Case Study A.2 might be used; if a commercial version (Appendix B) is not on hand an expedient version can be constructed using readily available materials provided a HEPA exhaust unit is available (see Case Study A.2). If at all possible these units should be vented to the outdoors to establish negative pressure in the room. If the HVAC serves only that room, then the supply air should be restricted or sealed off to establish a negative pressure in the room. If the HVAC serves other areas as well, both the supply and return-air grilles should be sealed off to prevent droplet nuclei from escaping the room, even though room temperature and humidity may suffer. If available measures cannot insure that droplet nuclei will be contained, these approaches should not be used.

Another strategy would be a "zone-within-zone" approach in which the patient is placed in a HEPA-ventilated full or partial enclosure that is maintained under negative pressure relative to the rest of the room. Partial and full enclosures are described in Case Studies A.2 and A.3, and some commercially available models are listed in Appendix B. In Case Study A.2 the enclosure is constructed around the upper (head) end of the patient's bed, and is extended to enclose the patient's torso. Air is exhausted near the patient's head, perhaps

using a ventilated headboard, and passes through a HEPA filter unit. This establishes a negative pressure zone within the enclosure. This approach has been shown to provide excellent containment for several angles of patient inclination even when crudely constructed (Case Study A.2). If at all possible the HEPA-filtered exhaust air should be vented to the outdoors to place the entire room under negative pressure; however, this may not be possible and recirculation to the room may be necessary. A second level of protection should then be provided by preventing room air from reaching other areas through the HVAC system or leakage points, as described above.

A full patient zone-within-zone enclosure may also be used. Case Study A.3 describes a simple enclosure established in a multi-patient room by replacing the privacy curtain with a plastic curtain extending from the ceiling to within ½ inch of the floor. The hem of the curtain is weighted with lightweight chain or other weights to minimize curtain movement during exhaust. A HEPA-filtered exhaust unit is attached through the curtain to draw air from inside the patient enclosure and maintain the enclosure under negative pressure relative to the rest of the room. At sufficiently high exhaust rates the system can also provide a degree of directional airflow if the HEPA intake is attached near one corner of the foot of the bed, and a gap is left open in the curtain at the head of the bed diagonally opposite the HEPA intake (Mead and Johnson, 2004). This allows the care providers to minimize their exposure by staying "upwind" of the highest particle concentrations. Case Study A.4 describes simultaneous exhaust of multiple patient enclosures using a manifolded exhaust system, which could be applied in a multi-patient room in which individual zone-within-zone enclosures had been constructed. As before, the HEPA-filtered air exhausted from the enclosure(s) should be vented to the outdoors if possible, and a second level of protection should be provided by preventing room air from reaching other areas through the HVAC system or leakage points.

Preparedness policy guidance suggests that when there is a shortage of AIIRs or a need to concentrate patients to make the best use of infection control resources, patients maybe be cohorted in a single AIIU rather than in AIIRs scattered over the hospital (CDC, 2004, Supplement C: Preparedness and Response in Healthcare Facilities). A good approach might be to dedicate an ward or entire wing to patient cohorting as described in Case Study A.5. In many facilities a ward or wing of the hospital may be served by a single HVAC system, and is physically isolated from other areas for fire control purposes. It may be possible to adjust the exhaust and supply air flow rates to place the entire area under negative pressure relative to adjacent areas of the hospital, and the limited number of entries to the space facilitates access and traffic control. If the HVAC system cannot be adjusted to provide adequate negative pressure, high-flow HEPA-filtered exhaust units may be set up in the space and exhausted to the outdoors. Rosenbaum et al. (2004) converted a 29,300 ft^3 physical therapy gymnasium to a 30-patient isolation ward by exhausting the space with multiple high-flow HEPA-filtered industrial "neg-air" units typically used in asbestos remediation work (for a discussion see Case Study A.5 in Appendix A). This

approach is efficient and minimizes some risks associated with using multiple AIIR/AIIU scattered over the facility. In the case of SARS, cohorting in some settings in Taiwan and Toronto was shown to interrupt disease transmission even in the absence of AIIR (CDC, 2004, Supplement I: Infection Control in Healthcare, Home, and Community Settings). It should be noted that heating or cooling demand on the HVAC systems serving the cohort space and adjacent zones may be significant, and the ability of the HVAC systems to handle the load should be evaluated in consultation with the facilities engineering personnel and through exercises under adverse weather conditions. Although cohorting is an effective option, single-patient AIIR/AIIU should also be kept available for certain patients, including those who may be a special risk (e.g. SARS "superspreaders") or whose disease status is still being evaluated (CDC, 2004, Supplement I: Infection Control in Healthcare, Home, and Community Settings).

III.D.2 Temporary Non-hospital Alternative Patient Care Facilities

When patient care needs, including isolation needs, exceed the available hospital capacity it may be necessary to establish non-hospital alternative patient care facilities. Warehouses, gymnasiums, convention centers, and other large area facilities have been proposed as possible sites. These offer opportunities for cohorting large numbers of patients in a single space, and placing the space under negative pressure via HVAC adjustments and high flow rate HEPA exhaust. Isolation of individual patients and small groups of patients could be accomplished using a zone-within-zone approach with commercially available or expedient enclosures. Case Study A.4 discusses the use of manifolded multiple-patient enclosures where space is available for them. The lack of handwashing, bath, and toilet facilities would be a challenge in such facilities, as would be the need to bring everything necessary for patient care to the site. Planning and preparation for setting up this type of alternative care site would be essential to its success.

University dormitories, hotels and motels, and other structures with in-room or in-suite handwashing, bath, and toilet facilities could be useful alternative sites. Hotels and motels are attractive because they are furnished, have linens on-hand, and may also have laundry and food preparation facilities.

A great difficulty in utilizing a non-hospital patient care facility is the need to equip the facility with the necessary medical equipment and supplies. Nursing homes and convalescent centers have some of this materiel on hand, including medical beds, and could also serve as overflow treatment and isolation sites provided their current patients could be relocated.

Use of any of these alternative facilities would require extensive prior planning and coordination, including the implementation of public health statutes and regulations providing public health agencies with the necessary authorities to require their availability and property owners with the necessary financial protections.

Chapter IV. Techniques for Evaluating AAIR and AIIU Performance

IV.A Pressure Balance Assessment

Air will move along a "pressure gradient" from an area of higher pressure to an area of lower pressure. The higher the pressure difference, the faster the air will move. Guidelines (AIA, 2001; CDC/HICPAC, 2003) require that AIIR ventilation systems maintain a differential pressure of at least .01 inches of water gauge (2.5 Pascals) to insure that air moves into the room through any openings to prevent droplet nuclei from escaping the room.

Air currents are always present both inside and outside an AIIR/AIIU. They are created by HVAC systems, by persons entering or leaving or moving around the space, and by temperature differences in the space. These air currents can overcome the directional airflow along the pressure gradient, especially at the doorway as it is opened and closed. Thermal gradients will also be present in the room, with air near the ceiling being warmer than the air near the floor. When a doorway is opened, air may flow into the AIIR/AIIU at the bottom of the doorway but flow *out* of the AIIR/AIIU at the top of the doorway. The pressure differential must be high enough to maintain directional airflow into the AIIR/AIIU over the entire doorway opening in spite of both drafts and thermal gradients (Wiseman, 2003). Both qualitative and quantitative assessments can be used to evaluate the adequacy of pressure differentials for achieving the containment goal.

IV.A.1 Quantitative Assessment Using Micromanometers

A manometer is an instrument used to measure pressure differential, i.e. the difference between two pressures. The device has two "taps" to which hoses may be attached, and the hose ends are then subjected to the two pressures being compared. In an AIIR or AIIU, one hose leads to the inside of the room, and the other end to the space outside the room. It does not matter where the instrument itself is located, since only the pressures at the hose ends are compared. *Note that no air flows through these hoses* – they merely transmit the room pressure to the instrument – nor does any air flow through the manometer. In practice, a manometer gauge with a visual alarm will be permanently mounted to the outside wall of an AIIR, perhaps with a tube leading from the back of the instrument into the AIIR via a hole drilled through the wall. The tube will be tightly sealed into the hole to prevent air leaks. Similar devices are also placed on laboratory chemical fume hoods and industrial containment hoods to verify the negative pressure differential required for proper system performance, and also across filters to indicate when they are dirty and have too much flow resistance (a manometer gauge will likely be found on a HEPA-filtered exhaust unit, for example). Analog manometers filled with water or mineral oil are used for high differential pressures such as those used in industrial systems (thus the common pressure units of "inches of water gauge" or "inches of water column"), but these

devices are not sensitive enough to reliably measure AIIR differential pressures of a few Pascals. Instead, highly sensitive electronic manometers employing pressure transducers are used. These can measure extremely low pressure differentials, and are also well suited to electronic alarm and control systems. Digital manometers are now the most common electronic manometers. A detailed discussion of manometers can be found in the Industrial Ventilation Manual published by the American Conference of Governmental Industrial Hygienists (ACGIH, 2004).

AIIR manometer measurements are straightforward because these rooms will have manometer alarms already in place. Such devices can also be installed in AIIU for continuous measurements, or a hand-held digital manometer can be used for periodic measurements provided there is a way to sense the interior and exterior pressures simultaneously. Drilling a hole through the doorway wall and sealing a length of tube into the hole on both sides of the wall, with hose projecting a few inches out from the wall on both ends, would allow this. The manometer could then be attached to the hose for the measurement from either side of the wall. The hose ends would be clamped or plugged when not needed to avoid an air leak.

IV.A.2 Qualitative Assessment Using Air Current Indicators

Differential pressure is only an indicator of contaminant containment performance potential in an AIIR or AIIU. Although it is generally agreed that .01 inches of water gauge (2.5 Pascals) is usually sufficient to maintain the correct air flow, there are simple qualitative techniques for verifying this. Essentially any sensitive means of determining the direction of air currents will work, but one of the best tools is artificial "smoke". "Smoke" generators produce a fine white mist that has the appearance of smoke and is neutrally buoyant, i.e. it neither rises nor sinks in air. The wisps of smoke move with the air and allow the air currents to be traced. This allows the evaluator to determine which direction air is moving in an open doorway, through cracks around a closed doorway or window, and in the space. It also is useful for detecting leaks.

The simplest and most inexpensive smoke generators are "air current tubes" or "smoke tubes". These are glass tubes filled with a reagent and sealed at both ends until use. When needed, the tube end tips are snapped off and a squeeze bulb is attached to one end. As the user squeezes the bulb a volume of air passes through the tube, reacts with the reagent to produce a white smoke-like mist of particles, and the mist exits the other end. Puffs of mist can be produced until the reagent is exhausted. Users must take care when using these tubes to avoid inhaling the mist, which is irritating to the respiratory tract.

Hand-held heated-element mist generators are also available. These battery-operated devices contain a cartridge of the liquid that evaporates when exposed to a heated element in the device then condenses to produce the mist. A continuous stream of smoke-like mist is produced as long as the trigger is depressed, though the cartridge will empty in about 5 minutes of continuous use.

The mist is less irritating than the squeeze-bulb type, but users should still avoid inhaling the concentrated mist. An example of this type of generator is shown in Figure A.2.2 of Case Study A.2. Some air current generator sources are listed in Appendix B.

IV.B Tracer Gas Measurement

Tracer gas measurement is a highly sensitive method for quantifying the amount of contaminant escaping from a space. The technique involves releasing a gas at a continuous rate inside the space and measuring how much gas shows up outside the space. Sulfur hexafluoride (SF_6) gas is often used because it is harmless, non-reactive, does not occur naturally in the atmosphere, and can be detected in extremely low concentrations. Tracer gas methods are often used to certify the performance of high hazard laboratory chemical fume hoods to make sure they contain the contaminant, and for indoor air quality investigations to measure dilution rates or trace the movement of air through a building. The downside of tracer gas measurement is that the detection equipment is quite expensive and requires some user training. While the cost might be justified for a contractor who certifies the performance of AIIR, fume hoods, and other containment systems on a regular basis, it is likely to be too excessive for one-time or occasional use in a health care facility. Examples of SF_6 systems and sources are provided in Appendix B.

IV.C Bioaerosol Simulant Measurement

Methods are available for sampling air to detect and identify airborne biological particles or "bioaerosols" (ACGIH, 1999). Unfortunately the methods are somewhat limited and are not appropriate for all organisms, especially viruses. Further, it would be impractical and dangerous to use actual pathogens in AIIR/AIIU performance evaluations during the planning and preparation process, and it is not necessary to do so. For purposes of determining whether droplet nuclei might escape AIIU/AIIU containment, any aerosol with the same aerodynamic behavior as the droplet particle can be used. The simulant and measurement technique must be chosen so that the simulant particles released into the AIIR/AIIU can be distinguished from the ever present background particles in the atmosphere. Some approaches are discussed in the following sections.

IV.C.1 Optical Particle Sensing

Airborne particles can be detected and their size measured by the way they interact with light. Optical particle counting and sizing instruments called aerosol spectrometers draw air into the instrument and pass it through a sensing chamber illuminated by a laser. When an airborne particle passes through the sensing zone some of the laser light is scattered, and the amount of light

scattered at a particular angle is measured by a photocell. The instrument is calibrated to know how much laser light a particle of a certain size, say 2 μm in diameter, will scatter at that angle. As the sampled air stream passes through the instrument it counts the number and size of the scattered light "blips" to determine how many particles of each size are in the air. The data are recorded by the instrument for later download to a computer. Battery-operated aerosol spectrometers suitable for field measurements can measure particles in up to 15 size categories over a size range as broad as 0.5-20 μm; in general, the price goes up with the number of size categories and the width of the size range (see Appendix B). Research grade laboratory aerosol spectrometers can measure many more categories and much broader size ranges, but these are generally quite expensive and are not well suited to field measurements.

AIIU design evaluations supporting development of this document were performed using aerosol spectrometers measuring over the 0.5-20 μm size range in 15 size categories as described in Case Studies A.2 and A.3 (see also Mead and Johnson, 2004). The AIIU was a zone-within-zone type of single patient enclosure inside a multi-patient room. Before releasing the simulant aerosol the room was purged of nearly all airborne particles in the 2-μm range by operating the HEPA exhaust unit for a period. The simulant aerosol was then generated inside the enclosure with a standard medical air jet nebulizer filled with a water suspension of uniformly-sized 2.1-μm diameter polystyrene latex microspheres. A total of 6 spectrometers were placed at locations inside and outside the AIIU zone-within-zone containment, and particle counts at each location were measured over a period of time. The numbers of 2-μm size particles inside and outside the containment during aerosol generation were then compared. These data demonstrated containment of the 2-μm particles by the AIIU. Additional studies could be performed to monitor changes in particle concentrations at various locations during simulated patient care and movement of personnel and materials in and out of the AIIU, to determine whether particles escape during these activities.

Although this technique has many attractive features, particularly the ability to link particle escape with activities, the measurement instrument costs would likely be too great for most preparedness budgets (see Appendix B). Additionally, the technique cannot be used with all AIIU designs. A spectrometer counts *all* particles of a given size, and cannot distinguish between a simulant intentionally released and naturally occurring atmospheric particles of the same size. The technique can only be used if it is possible to remove the background particles before releasing the simulant. For example, spectrometer measurements would not have been helpful during Case Study A.4 in which a multiple-enclosure system was erected inside a warehouse, because there was no way to remove the numerous background particles.

Although the optical particle sensing approach has limited utility, it can provide very valuable information when properly used. Best practices research to evaluate candidate AIIU designs, such as was performed for Case Study A.3, is an example of the potential value of the technique.

IV.C.2 Fluorescent Microsphere Sampling

Another approach to particle sensing inside and outside containments involves capturing the airborne simulant particles on filters using portable air sampling pumps and filter cassettes, transferring them to a microscope slide, and counting the number collected. As with optical sensing, however, the difficulty may be in distinguishing between the simulant particles and naturally-occurring particles of the same shape and size that are also captured and transferred to the slide. Bubbles in the slide mounting medium can also be difficult to distinguish from spherical simulant particles in the 1-5 μm size range, even when using a good-quality polarizing light microscope at maximum magnification of 1000x under oil immersion. Fluorescent microspheres provide a solution to these difficulties.

Suspensions of fluorescent uniformly-sized microspheres can be purchased for use as simulant bioaerosols (see for example Duke Scientific, Palo Alto, CA in Appendix B). The microspheres are available that fluoresce in red, green, or blue when illuminated with the right source light wavelength, and 1-5 μm particles can be readily seen under a fluorescence optical microscope. The green microspheres appear to be the easiest to see at low magnification. Modern fluorescence microscopes are fitted with digital cameras linked to computers with automatic image analysis particle sizing and counting software. With such a system it is possible to accurately count the number of particles of a particular size and fluorescence color present on a slide.

This technique is both technologically simple and highly sensitive. Air outside the containment, which is of primary interest, can be sampled for an extended period of time to maximize the probability of capturing simulant particles should they be present even in extremely low concentrations (Johnson et al., in preparation). The cost is also reasonable – the most expensive piece of equipment is the fluorescence microscope, though a high quality instrument may be less expensive than a single portable aerosol spectrometer. If a fluorescence microscope is already on hand in the facility then the cost is greatly reduced to only that of the air sampling pumps, filters, and other supplies (Appendix B). Since pumps may be available in the facility's environmental health and safety office, the cost may turn out to be that for filters and other supplies only.

Chapter V. Summary and Conclusions

Preparedness planning for response to a surge demand for airborne infectious isolation capacity is a challenge for health care facilities. The purpose of this document was to provide a review of current airborne infectious isolation guidelines, familiarize planners with the ventilation design principles and experience underlying the guidelines, discuss approaches to developing isolation surge capacity designs while recognizing that time and resources may limit the options, provide data-based recommendations for some expedient isolation system designs, and identify commercial sources for some useful equipment.

Planning for isolation surge capacity requires the joint efforts of a team of individuals with expertise in epidemiology, infection control, facilities engineering, patient care, safety, bioterrorism, and other areas. The approaches taken in a given facility will depend on that facility's patient care mission during a response as well as its physical characteristics, and the planning team will need to develop practical isolation solutions that meet their patient care needs and that are achievable in time and with the available resources. The material contained in this document is intended to assist preparedness planners by stimulating their thinking and facilitating design, development, and preparation of isolation surge capacity systems.

References

Otten JA and HA Burge (1999). Viruses. In: *Bioaerosols: Assessment and Control* (J Macher, Ed.). American Conference of Governmental Industrial Hygienists (AGCIH): Cincinnati, OH, pp. 21.1-21.6.

ACGIH (2004). *Industrial Ventilation: A Manual of Recommended Practice, 25th Edition*. American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

AIA (2001). *Guidelines for Design and Construction of Hospital and Health Care Facilities*. American Institute of Architects, Washington DC.

ASHRAE (2003). *HVAC Design Manual for Hospitals and Clinics*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

CDC (1994). Guidelines for Preventing the Transmission of *Mycobacterium tuberculosis* in Health-Care Facilities, Centers for Disease Control and Prevention. MMWR 43: RR-13, 28 October 1994.

CDC (2002). Draft Guide C, Part 1: Infection Control Measures for Healthcare and Community Settings, Centers for Disease Control and Prevention, 26 November 2002.

CDC (2004). Public Health Guidance for Community-Level Preparedness and Response to Severe Acute Respiratory Syndrome (SARS) Version 2, Centers for Disease Control and Prevention, Atlanta, GA, 8 January 2004.

CDC (2005). Draft revision to Guidelines for Preventing the Transmission of *Mycobacterium tuberculosis* in Health-Care Facilities, Centers for Disease Control and Prevention, accessed online 11 July 2005 at http://www.cdc.gov/nchstp/tb/Federal_Register/New_Guidelines/TBICGuidelines.pdf .

CDC/HICPAC (2003). Guidelines for Environmental Infection Control in Health-Care Facilities. Centers for Disease Control and Prevention and the Healthcare Infection Control Practices Advisory Committee. MMWR 52: RR-10, 6 June 2003.

DHSSCIC (1999). *Guidelines for the Classification and Design of Isolation Rooms in Health Care Facilities*. Department of Human Services Standing Committee on Infection Control, State of Victoria, Australia, July 1999.

English JF, MY Cundiff, JD Malone, et al. (1999). *Bioterrorism Readiness Plan: A Template for Healthcare Facilities*. Association of Professionals in Infection Control and Epidemiology and the Centers for Disease Control and Prevention, 13 April 1999. Accessed online 11 July 2005 at http://www.cdc.gov/ncidod/hip/Bio/13apr99APIC-CDCBioterrorism.PDF .

Garner, JS and Hospital Infection Control Practices Advisory Committee (1996). Guideline for Infection Precautions in Hospitals. *Infect Control Hosp Epidemiol* 17:53-80 and *Am J Infect Control* 24:24-52. Accessed on-line 15 July 2003 at http://www.cdc.gov/ncidod/hip/ISOLAT/Isolat.htm .

Gill, KE (1994). HVAC design for isolation rooms. *Heating/Piping/Air Conditioning* February:45.

GAO (2003). *Hospital Preparedness: Most Urban Hospitals Have Emergency Plans but Lack Certain Capacities for Bioterrorism Response*. GAO-03-924. Washington, DC, August 2003. Accessed on-line 7 July 2005 at http://www.gao.gov/new.items/d03924.pdf .

Johnson DL, RA Lynch, and K Mead (in preparation). Effectiveness Evaluation of Surge Capacity Airborne Infectious Isolation Units Using Simulant Aerosol. To be submitted to *Annals of Emergency Medicine*.

Marshall JW. (1996). Health Care Ventilation Standard: Air Changes per Hour or CFM/Patient. *American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Journal* September: 27-30.

Mead K and DL Johnson (2004). An Evaluation of Portable High-Efficiency Particulate Air Filtration for Expedient Patient Isolation in Epidemic and Emergency Response. Annals of Emergency Medicine 44(6):635-645.

Mead K and DL Johnson (2005). Experiments to evaluate the isolation effectiveness of a partial patient enclosure utilizing a recirculating HEPA-ventilated headboard. Unpublished data.

NJDHSS (2004). Influenza Surge Capacity Guidance for General Hospitals. State of New Jersey Department of Health and Senior Services, Office of the State Epidemiologist, Trenton, NJ, 9 November 2004.

NYSDOH (2003). New York State Department of Health Environmental Control Measures for Airborne Infection Isolation Surge Capacity Planning in Health Care Facilities for Smallpox, SARS or Other Infections Potentially Transmitted via Airborne Droplet Nuclei. New York State Department of Health, 18 December 2003.

Phillips M.L., C.C. Meagher, and D.L. Johnson (2001). What is "Powder-Free?" Characterization of Powder Aerosol Produced During Simulated Use of Powdered and Powder-Free Latex Gloves. *Occupational and Environmental Medicine* 58:479-481.

RACCDC (2004). *Isolation Rooms (Including Mechanically Ventilated Rooms): Best Practice Standards for Capital Planning*. Regional Advisory Committee on Communicable Disease Control, Belfast, Northern Ireland, 30 December 2004.

Rosenbaum RA, JS Benyo, RE O'Connor, et al. (2004). Use of a Portable Forced Air System to Convert Existing Hospital Space Into a Mass Casualty Isolation Area. *Annals of Emergency Medicine* 44(6):628-634.

Streifel AJ (2000). Health-care IAQ: guidance for infection control. *Heating/Piping/Air /conditioning* October:28.

Wiseman B (2003). Room Pressure for Critical Environments. *ASHRAE Journal* February:34-39.

Appendix A. Case Studies of Some AIIU Design Approaches

A.1 Airborne Particle Removal with Portable HEPA Filtration Unit

Purpose.

The purpose this case study was to demonstrate the effectiveness of a free-standing HEPA filtration unit in removing airborne particles in a single-patient room, and to explore techniques for increasing the removal rate through improved room air mixing.

Background.

CDC isolation guidelines allow the use of portable recirculating HEPA filtration units to increase droplet nuclei removal from isolation rooms. Dilution ventilation theory (see section III.B.1 above) indicates that in the absence of particle generation by a source in the room, the particle concentration should decrease in an exponential manner once HEPA filtration begins. The rate of decrease in a given room, measured as the particle "half-life" in the space, is determined by the volume of the room, the rate of HEPA filtration, and the amount of room air mixing. Good mixing increases the removal rate and shortens the half-life, while poor mixing has the opposite effect.

Approach.

A NuAire Clean Air Module Model NU-114-424 (Figure A.1.1) was placed in a room similar in volume to a single-patient hospital room. The room's floor plan and HEPA placement are shown in Figure A.1.2; the room volume was 1750 ft^3 and the HEPA flow was rated at 720 cfm, so that the HEPA filtration rate was approximately 25 ACH.

Four trials were conducted, each with a different mixing configuration. Zero, one, or two household air fans were placed at desktop height (30 inches or 75 cm) at various locations in the room to promote mixing as shown in Figure A.1.3.

For each trial, the HVAC system was shut off to prevent particles from entering the room with the HVAC supply air. Naturally-occurring or "background" aerosol was supplemented by generating neutrally buoyant mist into the room with an air current smoke tube. After a short mixing period the aerosol concentration was measured using a data-logging MIE DataRAM aerosol monitor (MIE, Thermo-MIE Corp., Smyrna, GA). This instrument gives an estimate of the overall aerosol mass concentration based on light scattering by the aerosol cloud as it passes through the instrument. The monitor was placed in the center of the room at desktop height (30 inches or 75 cm). Aerosol concentration was

measured for 12 minutes without the HEPA in operation to verify a steady aerosol concentration, then the HEPA was turned on and allowed to run for approximately 20 minutes as the measurements continued. The concentration data were downloaded from the DataRAM to a personal computer following each trial.

Results and Discussion.

A graph of remaining aerosol concentration as a fraction of the initial concentration present (the concentration before the HEPA was turned on), is shown in Figure A.1.4. The vertical axis showing Fraction of Initial Concentration is plotted on a logarithmic scale because the data will plot as a straight line on this scale if the concentrations decline exponentially.

Figure A.1.4 shows that the aerosol concentration decreased approximately exponentially for each trial as theory indicates should happen. The slope of each line is an indication of the rate of concentration decrease for that trial, and it did not appear from the graph that there was a substantial difference in the rates for the various mixing conditions. The aerosol half-life was about 2.0 minutes once the HEPA was turned on. The "effective ventilation rate", which takes into account the mixing effect, can be calculated from the half-life and the room volume (ACGIH, 2004), and in this case was about 600 cfm. For the HEPA's 720 cfm rated flow rate, the "mixing factor" is about 1.2 for all trials. This indicates that mixing was excellent in the room with or without the supplementary fans operating. If infectious droplet nuclei were being generated into this room at a rate of 1 per second, the expected equilibrium concentration for this effective ventilation rate would be only about 4 droplet nuclei per cubic meter of air.

The HEPA unit used in this study was purchased for approximately $2195 in 2004, and is of extremely sturdy all-metal construction. The manufacturer indicated that, because of the high HEPA filter surface area of about 8 square feet, the unit would normally require filter maintenance only once per year or once per two years at normal airborne dust levels. Less expensive units with flow rates as high or higher than that provided by this unit are currently available (see Appendix B), but may not be as well constructed and may have more frequent maintenance requirements due to smaller filters. Maintenance of HEPA filters is a significant cost issue, so these questions should be explored with vendors and manufacturers as various equipment options are considered.

Conclusions.

The free-standing HEPA filtration unit was shown to very rapidly remove particles from the air, and demonstrated the potential value of such units for augmenting HVAC particle removal and reducing care provider exposures.

Figure A.1.1 NuAire Model Nu-114-424 portable HEPA filtration unit. Cell phone on top of the unit is shown for scale.

Figure A.1.2 Room floor plan

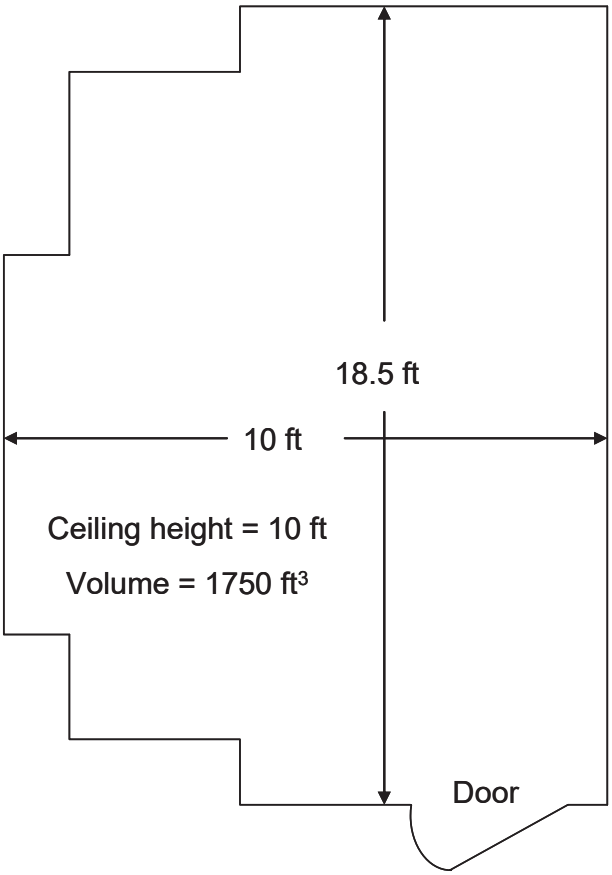


Figure A.1.3 Placement of the NuAire HEPA filter unit and DataRAM air monitor for each of four mixing configurations. A: One fan; B two fans opposing; C: two fans same direction; D: no fan.

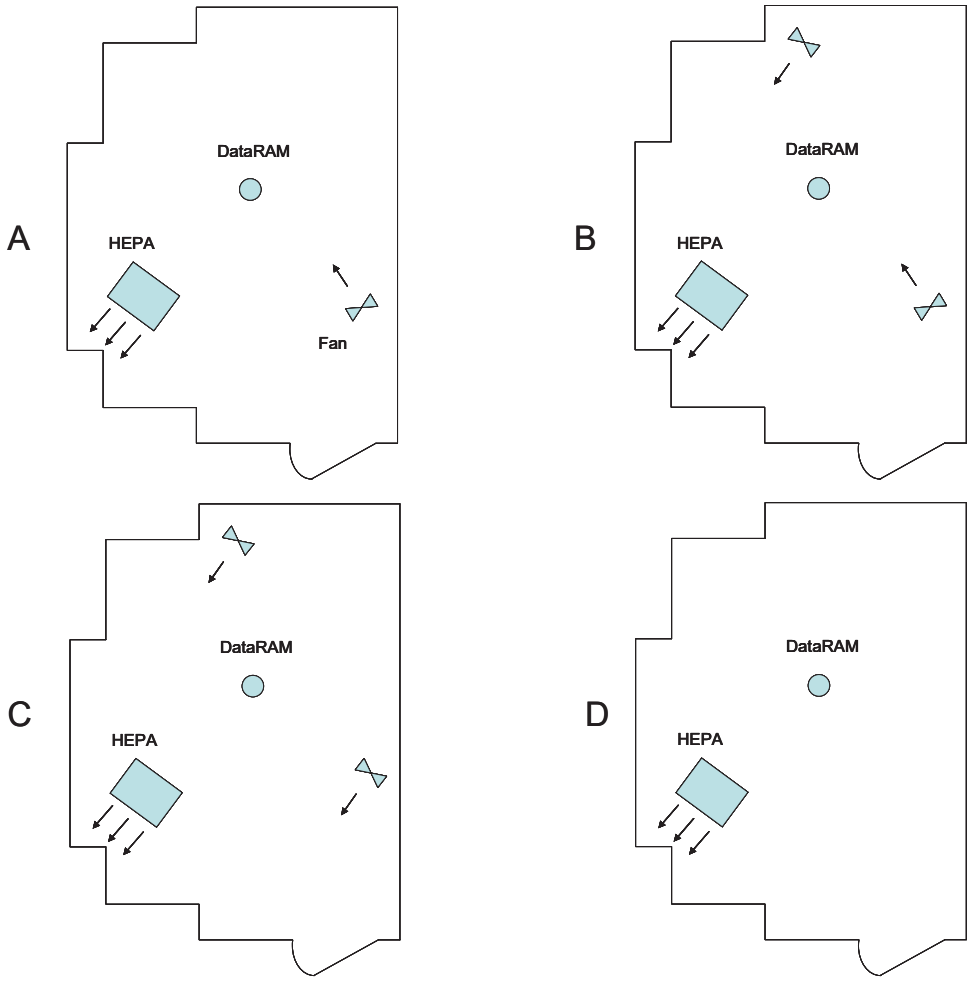
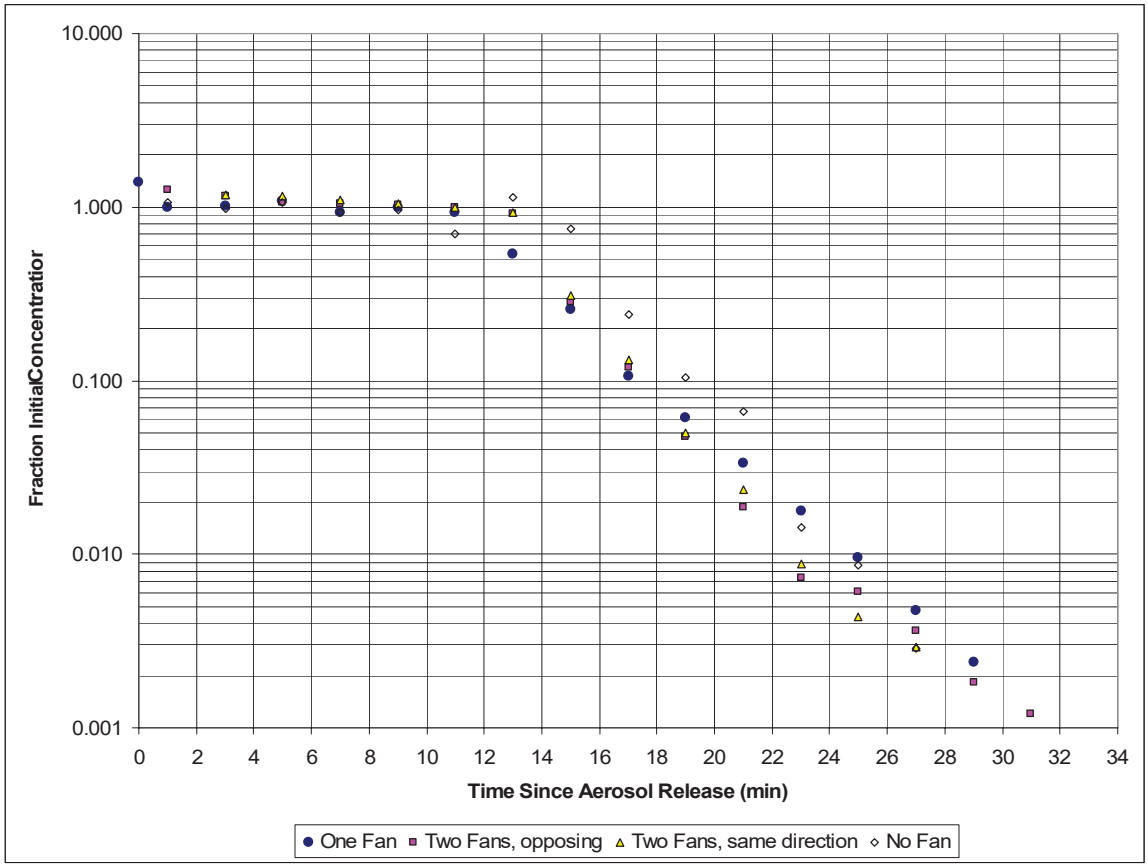


Figure A.1.4 Fraction of aerosol remaining vs. time for four mixing conditions



A.2 Exhausted Patient Bed Headboard with and without Partial Patient Enclosure

(Note: this work was conducted jointly with Mr. Kenneth Mead of NIOSH to obtain pilot data for his doctoral project research in the College of Public Health)

Purpose.

The purpose of this case study was to evaluate a prototype expedient ventilated patient head board, with and without a partial patient enclosure surrounding the patient's head and torso, constructed from readily available materials.

Background.

Portable recirculating HEPA filtration to reduce infectious droplet nuclei concentrations in treatment rooms was examined in Case Study A.1 and found to be highly effective for the conditions studied. Commercially available fixed units are also available that can be mounted in the ceiling or on the room wall to provide recirculating HEPA filtration. One version of the wall-mounted unit is a ventilated patient bed headboard with HEPA filtration and possibly UVGI as well. The intention in ventilating the headboard is to achieve a degree of directed airflow through the zone around the patient's head to carry droplet nuclei toward the headboard and away from care providers.

Experience with Industrial ventilation systems suggests that these devices would achieve little directed airflow at reasonable air flow rates. In contrast, the addition of side walls around the patient's head and torso would be expected to direct the airflow in a much more effective manner.

Approach.

The headboard shown in Figure A.2.1 was constructed in approximately 3 hours using a 2 ft x 4 ft x ¼ inch thick sheet of fiberboard, “2x4” wooden studs, 2 ft x 2 ft x 1 inch thick paper air conditioner filters, J-channel (for vinyl siding installation), a rectangular-to-round sheet metal take-off, and a 4-inch diameter flexible duct. All materials were obtained at a local home improvement store. The purpose of the paper filters was to provide enough flow resistance to create a uniform negative pressure within the space behind the filters, i.e. in the plenum, in order to obtain a uniform flow of air over the surface of the headboard. The flex duct connected the take-off at the bottom of the headboard (Figure A.2.1) to a NuAire Model NU-114-424 portable HEPA-filtered exhaust unit (see Figure A.1.1 of Case Study A.1). An adapter for the inlet side of the HEPA unit was constructed from ¼-inch fiberboard as well, with a 6-inch diameter “airtight” takeoff flange reduced to 4 inches for attachment to the metal flex hose (Figure

A.2.2). The headboard was suspended from the light fixture above a standard patient bed in a single-patient hospital room.

The headboard's ability to create a directed airflow was qualitatively evaluated using neutrally buoyant mist as shown in Figure A.2.3. The mist was generated at a distance of approximately 18 inches in front of the headboard, where the patient's head would be, and at closer distances from the headboard.

A partial patient enclosure was then constructed in about 1 hour using ¾-inch PVC plumbing pipe and fittings and 4-mil thick plastic sheet obtained at the home improvement store. The headboard with attached enclosure is shown in Figure A.2.4. The plastic sheet was tightly sealed to the headboard with clear packing tape. The sides of the draped plastic sheet extended to the floor. The enclosure was open on the foot end to allow air to be drawn across the patient's torso and breathing zone, into the headboard, and then to the HEPA unit for particle removal. The HEPA exhausted back into the room. The plastic was draped rather than being taped in place to allow care providers to move the plastic aside as necessary to reach the patient from either side, without placing any part of themselves except the hands and arms inside the enclosure or significantly affecting the directional airflow toward the headboard.

Particle capture was quantitatively assessed using a simulant aerosol and Grimm Model 1.108 aerosol particle spectrometers (see section IV.C.1 above for a discussion of optical aerosol sensing). After purging the room of airborne particles by operating the HEPA filtration unit for an extended period with the HVAC system shut off and the room door closed, an aerosol of uniformly-sized 1.6-µm diameter polystyrene latex microspheres (Duke Scientific, Palo Alto, CA) was aerosolized from water suspension in a standard medical air jet nebulizer placed at the patient head position. Particle count measurements were made at the bedside during nebulization periods of approximately 30 minutes with the head end of the bed inclined at 0, 25, or 45 degrees and with and without the partial enclosure in place. The data were then downloaded to a PC for comparison.

Results and Discussion.

The system flow rate was measured at the exit side of the HEPA and found to be approximately 175 cfm, which was considerably less than the 720 cfm rated flow capacity for the HEPA unit. The reduction was due to the greatly increased flow resistance caused by the headboard filters, flexible duct, and HEPA inlet adapter. The HEPA used a "squirrel cage" fan, and although these fans are quiet and provide high flow rates against low resistance, the noise increases and the flow rate drops as the resistance increases. At this flow rate the headboard provided no discernable directed airflow in the patient head area (Figure A.2.3).

In the absence of an attached enclosure, smoke tests indicated that the ventilated headboard provided no discernable directional airflow in the patient head area. Directional flow was not observed until the smoke was released within

6-8 inches from the headboard. This was consistent with what industrial exhaust ventilation principles and experience would predict – this type of hood configuration is not capable of "reaching out" any significant distance to capture air and draw it toward the hood. Although the flow rate used in this case study was somewhat lower than what might be provided by a commercially available equivalent (350 cfm compared to 150 cfm), this would not be expected to significantly improve the capture distance achieved by the headboard alone (ACGIH, 2004). Any effectiveness such a hood would have in establishing direction airflow would likely be due to the unit's exhaust if recirculated to the room, which could set up a general room air circulation that would carry air across the patient head area and toward the unit, or to the bulk movement of air through the room if the unit was exhausted to the outdoors.

Air flow into the partial patient enclosure opening was qualitatively evaluated with smoke and also measured using a heated wire air velocity meter (Alnor CompuFlow Model 8570 thermoanemometer). Velocities measured at 12 evenly spaced locations over the enclosure opening were consistent across the width of the opening and averaged approximately 20 feet per minute (fpm). Air flow through other openings into the enclosure (e.g. from under the bed along the sides) were not measured. Smoke tests indicated good directional air flow toward the headboard from at least 20 inches from the headboard, with rapid transit through the patient breathing zone area and directly to the headboard for bed inclination positions ranging from 0 to 45 degrees. This performance was also consistent with what is observed with similarly designed industrial "enclosing hood" exhaust ventilation systems.

Particle counts outside the enclosure during simulant aerosol generation could not be distinguished from the low background counts for any of the bed inclination positions. The counts remained below approximately 8 particles per liter of air while the enclosure was in place. In contrast, measurements made with the enclosure removed but with the headboard exhaust still operating rose linearly with particle generation time to approximately 580-1200 particles per liter depending on bed inclination.

Approximate costs for the exhausted headboard and partial patient enclosure are shown in Table A.2.1. Excluding the HEPA ventilation unit, the total cost for materials was only $118. A somewhat more rigid frame for the partial enclosure could be constructed using 1-inch PVC pipe and fittings, at insignificant additional cost.

Table A.2.1 Components, Sources, and Costs for the Single-Patient Partial Enclosure

Item	Quantity	Source	Cost*
¾-in PVC pipe	3 10-ft pieces @ $1.00	Home improvement or plumbing supply store	$3
¾-in PVC elbows	2 @ $,24	Home improvement or plumbing supply store	$1
¾-in PVC tees	2 @ $.19	Home improvement or plumbing supply store	$1
"Clear" polypropylene sheet, in 10 ft x 100 ft rolls	1 roll	Safety supply store	$ 32
Clear 2-in packaging tape	1 roll	Home improvement or hardware store	$3
4 in x 8 ft flexible metal duct	1	Heating & Air Conditioning supply or home improvement store	$14
6-in "airtight" flanged take-off	1	Heating & Air Conditioning supply or home improvement store	$6
Register box, 10 in x 4 in rectangular to 4 in round	1	Home improvement	$7
2 in x 60 ft duct tape	2 rolls @ $5.89	Home improvement or hardware store	$12
6-in to 4-in reducer	1	Heating & Air Conditioning supply store	$5
¼-in x 2 ft x 4 ft Fiberboard sheets	3 @ $3.00	Home improvement store or lumber yard	$9
2-ft x 2-ft x 1-in paper air conditioning filters	2 @ $4.97	Home improvement store	$10
2-in x 4-in x 92-in wooden studs	2 @ $2.35	Home improvement store or lumber yard	$5
½-in J-channel, 12 ft long	1	Home improvement store	$4
Latex indoor-outdoor caulking	1 tube	Home improvement or hardware store	$2
#8 x 2½-in wood screws	1 lb box	Home improvement or hardware store	$4
NuAire Clean Air Module Model NU-114-424	1	NuAire Corporation, Plymouth, MN	$2195
		Total cost =	$2313

* Item costs are rounded up to whole dollars

Conclusions.

The performance of the ventilated headboard system with and without an attached partial patient enclosure was consistent with industrial ventilation design principles and experience. Neither directed airflow nor particle capture were effectively established when only the headboard was in place. However, with the partial enclosure in place directional flow was well established and simulant aerosol particles did not appear to escape the containment for any bed position.

This expedient "zone-within-zone" ventilated headboard and partial patient enclosure system can be easily and quickly constructed using readily available materials. However, it does require that an appropriately sized HEPA-filtered exhaust unit be available. Industrial "neg-air" HEPA units used in creating negative pressure environments for asbestos remediation work are relatively inexpensive and widely available in a range of flow rates, and may even be on hand in some facilities for use by in-house asbestos remediation teams. Alternatively, portable HEPA units such as that used in this case study may be procured and adapters fabricated to allow their attachment to the enclosure system. These units also have the attraction of having day-to-day indoor air quality use in the facility to remove allergens and potentially infectious molds from the air.

Figure A.2.1 Expedient ventilated headboard without partial patient enclosure. A: Headboard with flow-distributing filters in place; B: headboard with flow-distributing filters removed to show bottom exhaust take-off.

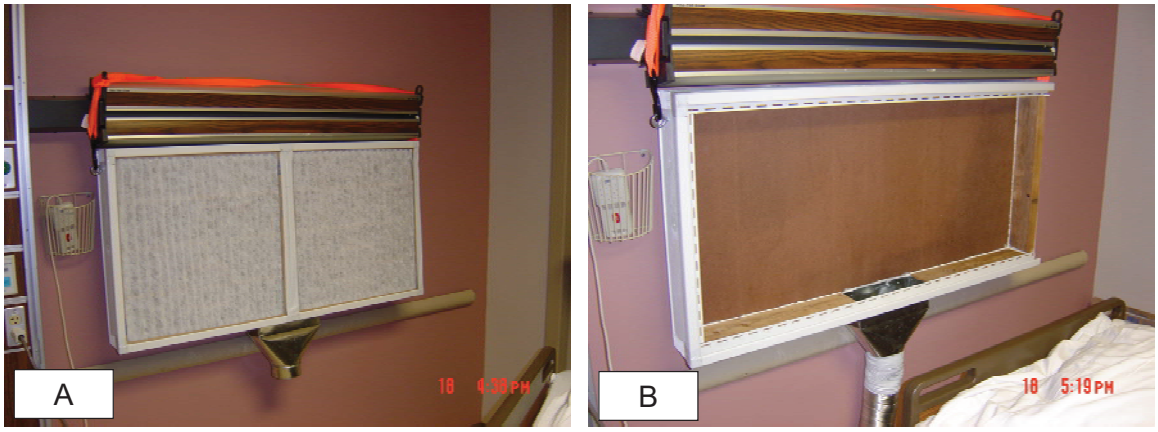


Figure A.2.2 HEPA inlet side adapter for connection to the ventilated headboard exhaust duct.

Figure A.2.3 Qualitative capture test using neutrally buoyant mist showing failure to provide directed air flow.

Figure A.2.4 Ventilated headboard with expedient partial patient enclosure in place. The flexible metal hose at left leads to the HEPA filter unit. The frame was constructed from ¾-inch PVC tubing and fittings; 1-inch tubing and fittings would provide a more rigid frame.

A.3 Single-patient Complete Enclosures in a Multiple-Patient Room

(Note: this work was conducted jointly with Mr. Kenneth Mead of NIOSH to obtain pilot data for his doctoral project research in the College of Public Health. A detailed discussion of the study is provided in Mead and Johnson, 2004)

Purpose.

The purpose of this case study was to evaluate the performance of zone-within-zone isolation enclosure designs for complete patient enclosures in multiple-patient hospital rooms.

Background.

A shortage of engineered single-patient AIIR may require that multiple-patient rooms be converted to AIIU use. As an alternative to cohorting in a shared space without isolation of individual patients, it may be possible to utilize expedient enclosures around patient beds to provide effective zone-within-zone isolation. The zone-within-zone isolation approach examined in Case Study A.2 with recirculation of HEPA-filtered exhaust air to the room was effective for a partial patient enclosure, and this approach could also be used in multiple-patient rooms. However, an alternative might be to enclose each patient entirely in a negative pressure HEPA-exhausted containment, in effect creating multiple AIIU within the room. A shared high-volume HEPA-filtered exhaust unit could serve all of the units simultaneously in a manifolded configuration, or individual HEPA exhausters could be employed. The multiple-containment approach would reduce cross-exposures between patients, which could be important for SARS or other illnesses subject to misdiagnosis because they have symptoms common to several diseases, and isolating individual patients in a shared room would also reduce the potential for care provider exposures as they move about the shared space.

Approach.

A hospital room capable of housing up to three patients was modified by replacing the standard privacy curtains with 4-mil thick plastic sheet. The sheet was attached to the ceiling curtain tracks using the same hooks used for the standard curtains, and was extended to within ½ inch of the floor. The hem of the curtains was weighted so they would hang straight and not be moved by air currents.

Containments were erected around two adjacent patient beds as shown in Figure A.3.1. In one trial the NuAire Model NU-114-424 HEPA-filtered unit (see Figure A.1.1) exhausted only one of the enclosures, while in another trial the unit

exhausted both enclosures simultaneously. HEPA-filtered exhaust air was recirculated back to the shared space.

Particle containment was evaluated by generating a simulant aerosol of uniformly sized 1.6-μm diameter polystyrene latex microspheres into one of the enclosures as in Case Study A.2. The medical air jet nebulizer was placed at the patient head position and filled with a water suspension of the microspheres. After purging the room of background particles by operating the HEPA for 45 minutes, aerosol was generated into the enclosure and airborne particle concentrations were measured inside and outside both enclosures over a 30-minute nebulization period using Grimm Model 1.108 aerosol spectrometers. Tests were conducted while exhausting only one enclosure and while exhausting two enclosures simultaneously.

Results and Discussion.

The total HEPA unit flow rate was measured at 550 cfm under these conditions, which provided 13 ACH of filtration for the room as a whole. However, within the enclosures the filtration rate was 32 ACH when exhausting both enclosures simultaneously or 65 ACH when exhausting only one enclosure.

Initial trials were conducted with the curtains drawn completely closed, but the final trials were conducted with the curtain left open slightly at the head end of the patient bed (Figure A.3.2). A 10-inch gap in the curtain provided a path of least resistance for air flow into the enclosure, and set up an observable directed air flow from the gap, across the patient bed, and into the HEPA unit located on the other side of the bed at the foot end (Figure A.3.1).

Results of particle measurement studies demonstrated that when both enclosures were simultaneously exhausted it was necessary to have a 10-inch curtain gap. Without the gap the aerosol escaped containment in the source enclosure and traveled to both the other exhausted enclosure and the general room atmosphere. It was also necessary to strictly separate the two enclosures when manifolding them to the HEPA unit. This was accomplished by taping a partition vertically down the middle of the HEPA inlet so that particles could not move between the partitions at the HEPA unit.

The possible influence of HVAC supply air on containment performance was also examined during the single-enclosure trials. Like many hospitals, the HVAC inlets were located in the ceiling near the windowed wall, and both of the enclosures were along the wall. Trials with the HVAC supply air vents open and sealed off showed no adverse effect of this supply air on the enclosure containment performance.

The simple containments constructed in this case study were highly effective in maintaining particle containment. Particle concentrations inside the second containment and outside the two containments could not be distinguished from background with the HVAC supply vents either open or closed. These results are described in more detail in Mead and Johnson (2004).

Approximate costs for the single-patient complete enclosures are shown in Table A.3.1. Excluding the HEPA ventilation unit, the total materials cost of the two enclosures was approximately $60.

Conclusions.

These case study results demonstrated the containment efficiency that can be attained using expedient zone-within-zone single-patient complete enclosures inside a multiple-patient room. The containments were quickly constructed using inexpensive and readily available materials. As discussed in Case Study A.2, the system does require that an appropriately sized HEPA-filtered exhaust unit be available. Industrial "neg-air" HEPA units could be used if on hand or portable HEPA units might be procured in the response planning and preparation stage. Procurement of these devices would allow advance fabrication of adapters and other fittings needed to attach them to the enclosures.

Table A.3.1 Components, Sources, and Costs for the Two Manifolded Single-Patient Complete Enclosures in a Multi-patient Hospital Room

Item	Quantity	Source	Cost*
"Clear" polypropylene sheet, in 10 ft x 100 ft rolls	1 roll	Safety supply store	$ 32
Tenso utility chain	50 ft @ $.50/ft	Home improvement or hardware store	$25
Clear 2-in packaging tape	1 roll	Home improvement or hardware store	$3
NuAire Clean Air Module Model NU-114-424	1	NuAire Corporation, Plymouth, MN	$2195
		Total cost =	$2255

* Item costs are rounded up to whole dollars

Figure A.3.1 Plastic sheet containment curtains erected around adjacent patient beds in a multiple-patient hospital room. Hem weights had not yet been added. A HEPA-filtered unit exhausted only one unit or both units simultaneously in the experiments, and recirculated filtered air to the room.

Figure A.3.2 A 10-inch opening in the curtain near the head of the patient bed allowed some directional airflow to be established diagonally across the patient and toward the HEPA unit at the foot end of the bed. Also shown in the photo are three of the Grimm aerosol spectrometers – one on the bed and one at provider nose height inside the enclosure, and one on the meal tray table outside the enclosure.

A.4 Manifolded Multiple Patient Enclosures for 3 or More Patients in a Warehouse, Gymnasium, or other Large Volume Facility

Purpose.

The purpose of this case study was to evaluate the material and equipment requirements for constructing an expedient multiple-patient enclosure system for isolating patients in a warehouse, gymnasium, or other large volume alternative care site.

Background.

In a severe airborne infectious isolation surge situation it may be necessary to isolate patients in alternative care sites away from hospitals. School gymnasiums, warehouses, and even convention centers have been suggested as possible sites. It would be helpful in such situations to be able to isolate individual patients in negative pressure enclosures to minimize the concentration of infectious droplet nuclei present in the general environment.

Approach.

A 3-module candidate AIIU design intended for construction in a large interior space, such as a gymnasium or warehouse, was constructed. The goal was to estimate the materials and equipment requirements for a unit capable of providing multiple single-patient complete isolation enclosures to be exhausted by a single HEPA unit.

The structure shown schematically in Figure A.4.1 was constructed in a medical warehouse. The frame was made from 1.5-inch diameter PVC plumbing pipe and fittings (Figure A.4.2), and the ceiling and walls were formed using 6-mil thickness polypropylene sheeting commonly used for constructing asbestos remediation enclosures. Although the transparent 4-mil thick plastic sheeting used in other case studies could also have been used, but opaque polypropylene sheeting was preferred for this application due to its greater strength. The wall-floor, wall-wall, and wall-ceiling seams were sealed with duct tape. The front of each module was a partial retractable curtain that extended from floor to ceiling. The curtain bottom was weighted with lightweight utility chain hemmed into the curtain base with duct tape. When closed a gap of 11 inches remained open to allow provider access without overly disturbing air in the enclosure due to curtain movement, and also to provide a low-resistance path for makeup air movement into the module as it is exhausted (Mead and Johnson, 2004). The curtain base was not taped to the floor, so that it could be opened wider when necessary. The center module was equipped with an anteroom, with gapped curtains at both the anteroom entrance and the anteroom-module entrance, with the gaps on

opposing sides of the entrances (Figure A.4.1). Each module was approximately 8.5 ft x 12.5 ft in plan with an 8.5-ft ceiling. The anteroom was 4.5 ft x 8.5 ft in plan with an 8.5-ft ceiling.

The modules were placed under negative pressure ventilation using a HEPA-filtered industrial “neg-air” exhauster connected by a manifolded and damper-controlled duct system to the modules (Figure A.4.3). The HEPA-filtered air was released back into the warehouse space. The branch dampers were used to adjust the flow rate of each module to be equal at 225 cfm, as measured at each module's exhaust using a heated wire air velocity meter (Alnor CompuFlow Model 8570 thermoanemometer). This was equivalent to a ventilation rate of approximately 15 air changes per hour (ACH) for these modules. A photograph of the completed prototype is shown in Figure A.4.4.

After the initial construction, the structural elements were labeled and the system was deconstructed and stored. After approximately one month the unit was re-erected in a new location by one of the two original participants and a new, untrained participant.

Results and Discussion.

The prototype system required several days to construct during the first build due to the need to cut and fit the PVC pipe frame members, tape all of the joints, and then apply the polypropylene ceilings and walls one sheet at a time. A total of approximately 500 ft of tubing, 80 sanitary crosses (4-way connectors), 6 tees, 12 elbows, and 2000 ft^2 of polypropylene sheet were used, though there was some wastage due to trial and error fitting. Three tight-sealing rubber-gasketed 6-inch dampers (R.L. Williams Co., Edmond, OK), 25 ft of 6-inch wire-reinforced flex duct, 50 ft of 12-inch wire-reinforced flex duct, and 8 rolls of duct tape were also used. Except for the dampers, all materials were locally purchased from items in stock at plumbing and safety supply stores. Approximate costs are shown in Table A.4.1. The neg-air exhauster was borrowed from the medical warehouse owner.

Re-erection of the unit by one experienced person and one inexperienced helper required two days. A substantial portion of this time was consumed in cutting the plastic panels used to cover the walls and ceilings. This construction time could have been reduced if pre-cut and numbered panels had been available.

Table A.4.1 Components, Sources, and Costs for the Expedient 3-Module Manifolded Enclosure

Item	Quantity	Source	Cost*
1.5 in PVC water pipe, in 10-ft lengths	60 @ $4.30	Plumbing supply or home improvement store	$258
1.5 in PVC sanitary crosses	80 @ $2.30	Plumbing supply or home improvement store	$184
1.5 in 90-degree PVC elbows	12 @ $.63	Plumbing supply or home improvement store	$8
1.5-in PVC tees	6 @ $.93	Plumbing supply or home improvement store	$6
PVC cement	1 can	Plumbing supply or home improvement store	$5
PVC primer	1 can	Plumbing supply or home improvement store	$4
"Clear" polypropylene sheet, in 10 ft x 100 ft rolls	3 rolls @ $32	Lone Star Safety Supply, Oklahoma City, OK	$96
6-in tight-sealing butterfly dampers, Naitor Product ID-1090	3 @ $62.25	R.L. Williams Co., Edmond, OK**	$187
12 in x 12 in x 6 in furnace Y junctions	2 @ $17.34	Heating & Air Conditioning supply store	$35
6-in adjustable sheet metal elbow	1 @ $1.43	Heating & Air Conditioning supply store	$2
10 in to 6 in sheet metal reducer	1 @ $6.57	Heating & Air Conditioning supply store	$7
12 in to 10 in sheet metal reducer	1 @ $7.44	Heating & Air Conditioning supply store	$8
6 in wire-reinforced and insulated flex duct	1 box of 25 ft	Grainger Industrial Supply	$25
12 in wire-reinforced flex duct	1 box of 25 ft	Grainger Industrial Supply	$14
Self-tapping #8 x 5/8 in sheet metal screws	1 pkg of 100	Home improvement or hardware store	$4
Tenso utility chain	25 ft @ $.50/ft	Home improvement or hardware store	$13
Duct tape	8 rolls @ $5.89	Home improvement or hardware store	$48
Industrial HEPA-filtered "neg-air" unit, 750 cfm	$900	Asbestos remediation supply stores	$900
		Total cost including neg-air unit =	$1804

* Costs are rounded up to whole dollars.
** These were special-order items. Off-the-shelf butterfly dampers for exhaust gas flue pipes do not have tight-fitting seals but could be adequate for this use, at greatly reduced cost.

Conclusions.

The 3-module manifolded isolation system was simple to construct using readily available materials at a cost of approximately $1800 including the HEPA-filtered neg-air unit. The only components requiring pre-ordering were the neg-air unit and the tight-seal dampers for controlling air flow from each of the modules. Although dampers that are locally available from heating and air conditioning or home improvement stores do not have these tight seals, they would likely be adequate to achieve the necessary flow balance and would be dramatically cheaper than the custom-built dampers.

The commercial neg-air exhauster provided 15 ACH of ventilation in these room-sized modules at its flow rate of about 675 cfm, but much higher ventilation rates and more directed airflow would be achievable using an exhauster flowing in the 2000+ cfm range. These units are only slightly more expensive than the lower-flow units, and are switchable between low and high speeds to give a range of flow rates typically from 1300-2100 cfm.

The time required to construct the unit given pre-cut and numbered structural components was two days, but this could have been reduced to perhaps one day if the polypropylene side and ceiling panels had been pre-cut and numbered as well.

Figure A.4.1 Schematic representation of the 3-module expedient isolation system erected in a medical warehouse. Only one anteroom was constructed for the prototype; an actual unit would have an anteroom on each module.

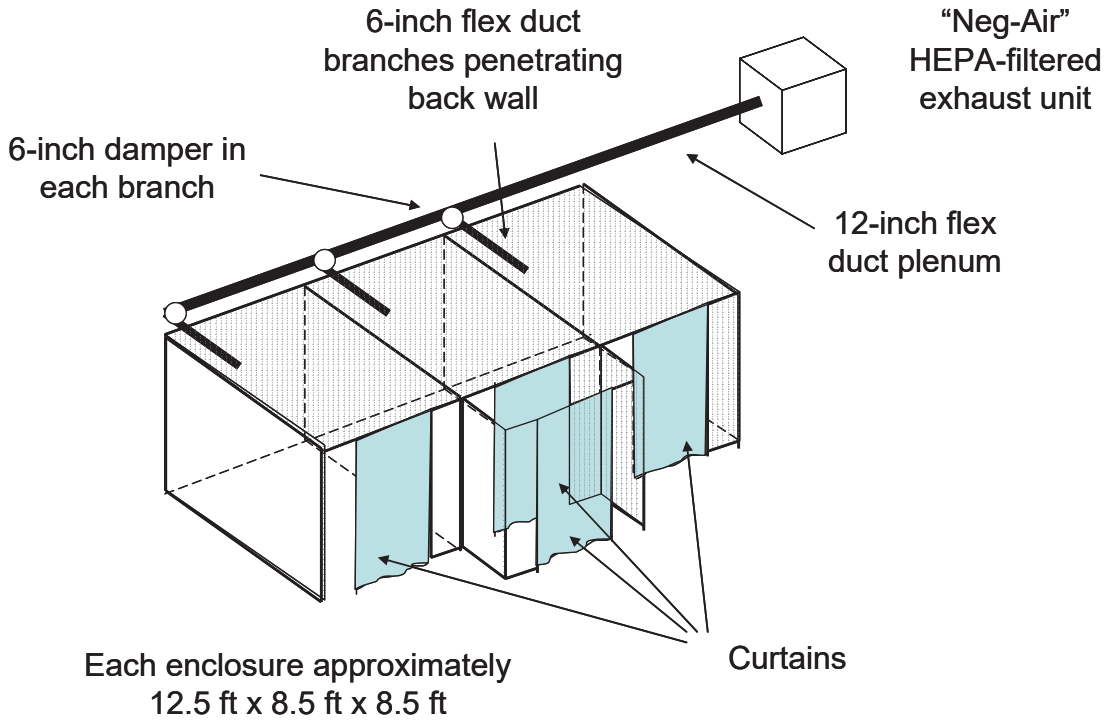


Figure A.4.2 The 3-module unit frame constructed from 1.5-inch PVC pipe and fittings. The anteroom frame has not yet been added. The joints were taped with duct tape before adding the polypropylene sheet walls and ceiling.

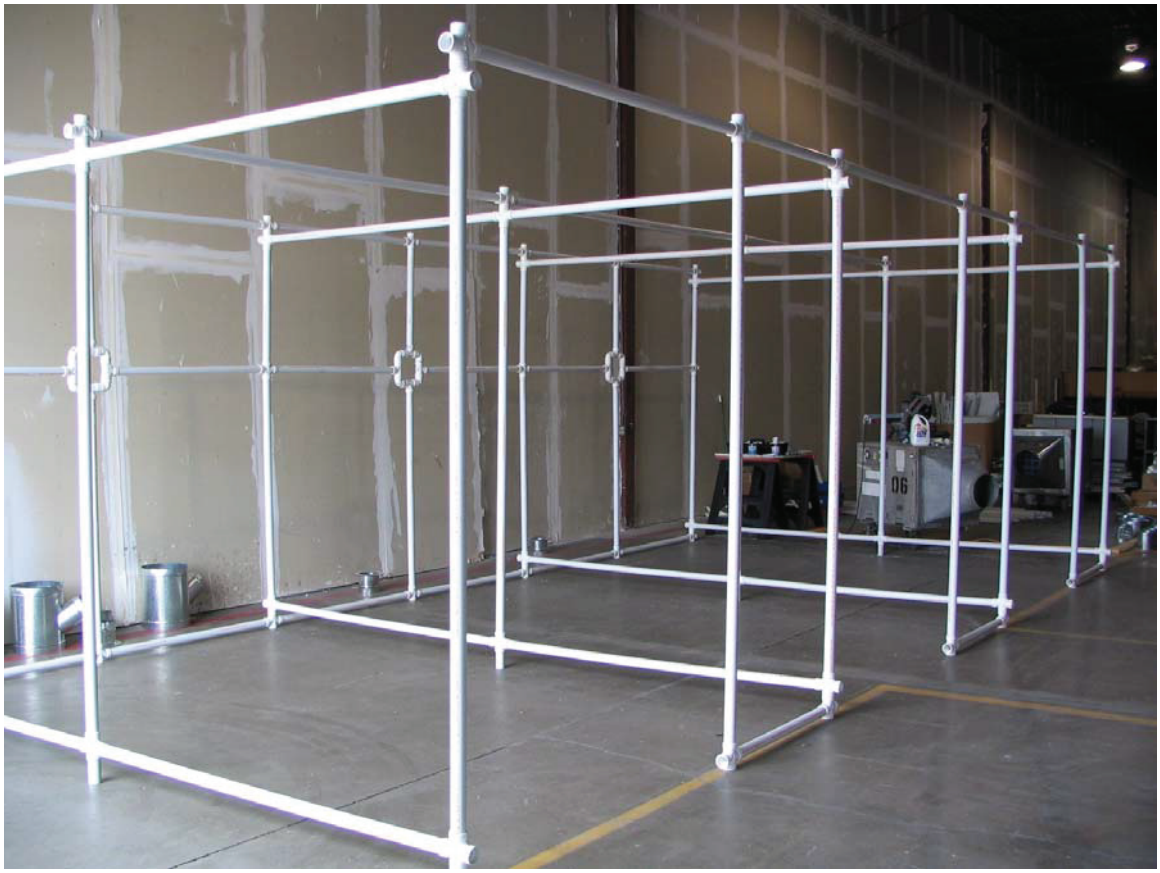


Figure A.4.3 View of the rear wall exhaust ports, 6-inch dampers and branch ducts, 12-inch main duct, and neg-air exhauster.

Figure A.4.4 Front view of the completed 3-module unit. Only one anteroom, on the center module, was constructed.

A.5 Negative Pressure Cohort Patient Care Areas

Purpose.

The purpose of this case study is to review results reported in the literature on conversion of a large-volume hospital area for use as a negative pressure isolation patient care area (for a detailed account see Rosenbaum, Benyo, O'Connor et al., "Use of a Portable Forced Air System to Convert Existing Hospital Space Into a Mass Casualty Isolation Area", *Annals of Emergency Medicine* 2004; 44(6):628-634).

Background.

One potentially rapid response to a large surge in isolation demand would be to convert an area of the hospital such as a single large room or open ward into a negative pressure isolation area. Hospitals are served by multiple HVAC units, often with an HVAC zone corresponding to a wing, section of a floor, or single large room that is also is physically separated from adjacent areas with fire walls and other barriers. Fire protection planning compartmentalizes the structure to prevent fire spread, and these features allow large areas to be essentially shut off from adjacent areas by closing doors and dampers and adjusting HVAC system supply and return flows. It may be possible to establish a negative pressure differential between the AIIU and adjacent areas through HVAC flow adjustments, but negative pressure can be readily achieved by exhausting air from the space through a HEPA filter to the outdoors. A team of mechanical engineers, occupational safety and health personnel, physicians, industrial hygienists, construction personnel, and emergency response planners in Delaware took this approach in developing response plans for rapidly converting a hospital physical therapy gymnasium into a 30-patient cohort care area.

Approach.

The physical therapy gymnasium modified to an AIIU had a floor area of 2930 ft^2 and a volume of 29,300 ft^3. Adjacent areas included a gymnasium waiting area, staff work area, and toilet/hydrotherapy room. Doorways allowed entry from the outdoors without passing through the hospital. The planners studied the HVAC systems serving the gymnasium and surrounding areas as well as the physical layout of the structure. Sheet metal blanks were fabricated to allow HVAC return air grilles to be sealed off to prevent gymnasium air from traveling to other areas of the facility. Supply vents were left open to provide conditioned makeup air to the space.

The negative pressure differential was established using up to four high flow rate (1000-2000 cfm each) industrial HEPA-filtered exhaust units. The HEPA-filtered exhaust was vented to the outdoors through a plywood panel

tightly fitted to a door opening. The insert was penetrated by four 12-inch diameter ducts with sliding dampers. Each HEPA unit was attached by a 12-inch flexible duct to one of the door insert penetrations. When a HEPA unit was not in use the sliding damper for that duct was closed.

The waiting area was converted to an anteroom entry from the hospital, and the outside entry was designated for patient and EMS entry. The staff work area and toilet/hydrotherapy area were isolated from the gymnasium patient care area for staff use.

After the planning and preparation were completed an operational test was conducted to see how long it would take to accomplish the conversion, assess how effectively isolation was achieved, and evaluate noise levels produced by the industrial exhausters.

Results and Discussion.

The operational test showed that the gymnasium conversion to a cohort AIIU could be accomplished by six staff members in about one hour, with minimal assistance by two other staff. A pressure differential of .018 inches of water gauge (4.5 Pascals) was achieved with two exhausters operating on their high speed setting, and the ventilation rate was calculated to be 8.2 ACH. 12 ACH and a differential of .032 inches (8.0 Pascals) was achieved with three exhausters operating on high, while 16.4 ACH and a differential of .052 inches (13.0 Pascals) resulted with all four exhausters operating on high. Noise levels at this highest flow setting were measured at 76 decibels, which is somewhat high for a patient care environment. By setting all four exhausters on their low flow setting the noise level was reduced to 70 decibels while maintaining 8.2 ACH of ventilation and a .032-inch (8.0-Pascal) pressure differential.

The only facility modification required was the installation of electrical circuits capable of supporting all current demands of the exhausters. Each unit required 115 volts and 13 amps of current, so four dedicated 20-amp emergency power circuits were installed. The total cost of the project was under $6000, including the cost of the four HEPA-filtered exhaust units, ducts, dampers, adapters and inserts, and new electrical circuits.

Conclusions.

This highly successful project demonstrated the utility and cost effectiveness of interdisciplinary and creative planning and preparation, and represents the ideal approach to AIIU design, development, and evaluation.

Appendix B. System Components, Sources, and Costs

A Microsoft Access® database containing system component source and cost information for isolation-related supplies and equipment can be found at http://www.coph.ouhsc.edu/coph/oeh/OSDH%20Isolation%20Database.mdb. The database is under continual development, and recommendations for additions are appreciated. Recommendations for additions may be sent to David-Johnson@ouhsc.edu.

Disclaimer: Listing of items and vendors in the database does not imply endorsement by the author, the Oklahoma State Department of Health, or HRSA. These listings are provided for informational purposes only.