In-Depth Report

Expedient Methods for Surge Airborne Isolation within Healthcare Settings during Response to a Natural or Manmade Epidemic

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Chapter I

Introduction and Literature Review

History: Airborne Disease Transmission Theory

Throughout recorded history, mankind has used concepts of "isolation" as a means to protect the larger population from exposure to those with a potentially infectious disease. Biblical references in the books of *Numbers* and *Leviticus* delineate instructions to both cover the mouth and send from the encampment any individuals thought to have leprosy or other infectious health "issues" [McMillen and Stern 2000]. The instruction to "cover the mouth" appears to guard against some form of droplet spread. The Centers for Disease Control and Prevention (CDC) still is not certain how leprosy is transmitted, though droplet spread is the most likely means [CDC 2003a]. This concept of separating potentially infectious persons from the general population has remained a predominant protection mechanism throughout much of the world's history [CDC 2003b], even when knowledge of the mechanisms responsible for the spread of disease or infection is lacking.

In the mid-1800s, the microorganisms responsible for infection were popularly believed to spontaneously generate; little thought was given to routes of contamination. In 1858, fueled by insight gained during studies of alcohol fermentation, Louis Pasteur debunked the spontaneous generation theory. Through experiments using his swan-necked flask (Figure 1), he was able to demonstrate that it was not the air itself upon which the causative organisms for spoilage and putrification rode, but microscopic dust particles *within* the air [Cohn 2004].

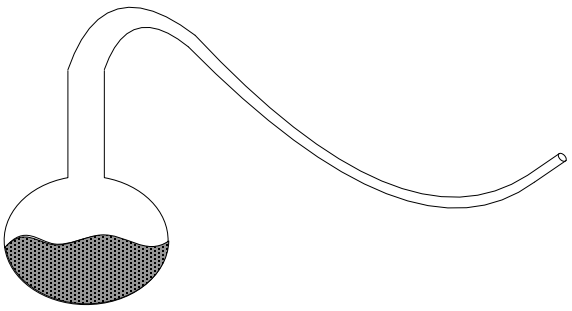


Figure 1. Swan flask. The swan-like neck was open to air, but dust and airborne microbes could not navigate the contour to reach the contents.

Although the focus of Pasteur's work was the prevention of spoilage of food and wine, the discovery had a great impact upon medical practices in Europe, especially as they pertained to patient infections due to open wounds or surgery. In the mid-1860s, Joseph Lister applied Pasteur's theory to his medical practice in Glasgow, Scotland. His first application was in the treatment of compound fractures, where Lister decided to apply dressings saturated with a carbolic acid "creosote" to kill the

germs in the wound and prevent other germs from entering. Inspired by his success, he applied the concept during the postoperative treatment of surgical amputations, reducing the mortality rate from 46 to 15 percent [Newsom 2003]. Lister's next assault against airborne microorganisms was the evolution of his "antiseptic surgery" technique, a surgical room treatment that aerosolized a 20 percent carbolic acid spray during the procedure and introduced the use of air filtration into medical practice [Meers 1993].

While Lister's efforts focused on preventing infectious microorganisms from reaching the vulnerable patient, recognition in the literature that air was a potential route of infectious transmission began to influence the treatment of contagious disease, both in Europe and in the United States. This influence was further fostered by Florence Nightingale's *Notes on Nursing,* in which she suggests that "…to keep the air he [the patient] breathes as pure as the external air, without chilling him" is the very first canon of nursing. Nightingale's instructions were based upon her own observations and intuitive epidemiological analysis. They place special emphasis on identifying fresh sources of room air and admonish against recirculating air from the "infected atmospheres" surrounding other ill patients or from other unhealthy sources [Nightingale 1860]. Nightingale was generally credited with recommending the use of pavilion-style hospital designs, which became popular in the United States and Europe. This design utilized multiple, small hospital rooms centered around an open inner courtyard [Larson 1997]. The multiple wards reduced the number of individuals exposed to any one patient, and the courtyards provided a ready source of fresh outdoor air.

For the hospital environment, the desire to separate the infirm was countered against the need to centrally locate them near the available healthcare providers. These competing requirements eventually led to the formation of the Sanatorium (a.k.a. Isolation or Infectious Disease Hospital), whereby the patients could be sufficiently separated from the population yet adequately clustered to allow access to healthcare. In Europe, these hospitals generally treated patients with typhoid, cholera, smallpox, and tuberculosis. The sanatoriums began to fully proliferate after Robert Koch discovered the tubercle bacillus in 1882 and, because the initial site of infection was the respiratory tract, speculated that tuberculosis was spread via airborne transmission [Newsom 2006]. However, Brehmer was credited with being the first to use a sanatorium, at Goorbersodorf, Germany, in 1859, but there are earlier references to a sanatorium in Bodington, England, in 1840 [History of TB 2004]. Within the United States, the first documented recommendations for isolation precautions appeared in a hospital handbook published around 1877. This handbook recommended placing infectious disease patients in separate facilities away from the main hospital; thus, it too adopted the sanatorium or infectious disease hospital approach [Garner 1996]. The first known application of this approach in the United States was a facility that opened in 1885 at Saranac Lake, NY [History of TB 2004].

The unfortunate consequence of the sanatorium approach was a dangerous and often fatal environment for healthcare workers and patients, due to cross-infections resulting from poor hygiene practices and a lack of disease-specific separation [Gammon 1998]. As observations of cross-infections increased, some hospitals

began instituting disease-specific separation by ward or by floor in addition to increasing emphasis on the evolving knowledge associated with aseptic practices [Garner 1996]. Despite these developments, the airborne route for potential cross-infection was not recognized universally by practitioners and medical facilities.

While some health professionals began to look at airborne dust as the primary carrier of most infectious diseases, others in Europe and the United States focused on other routes of transmission. In 1843 in Boston, Dr. Oliver Wendell Holmes, Sr., was proclaiming the virtues of hand and instrument hygiene among physicians, as a preventive measure against contact transmission of puerperal fever and other diseases. At the time, the concept of infection being transferred from patient to patient via the physician brought him great ridicule, although independent confirmation of the theory five years later by Vienna's Dr. Ignaz Semmelweis softened this criticism [Gathright 1995]. The famous epidemiological and investigational work by John Snow in the Broad Street Pump Outbreak of 1854 resulted in the discovery of cholera's transmission via contaminated water rather than an airborne vehicle, as was previously believed [Snow 1855]. In the late 1800s, malaria and yellow fever were both determined to be transmitted by mosquitoes. Thus, for several diseases whose transmission was originally thought to occur through the air, alternative explanations were discovered. History reflects that the pendulum of belief began to swing away from airborne transmission as a route of disease transfer.

The controversy about the effectiveness of airborne isolation and contact prevention continued into the 20th century. In the United States during the early 1900s, there were two common methods for aseptic nursing of patients requiring infectious isolation: (1) the barrier system, which involved multi-patient rooms and a strict emphasis upon contact precautions via the use of barriers such as gloves and gowns, and (2) the cubicle system, which adhered to the contact precautions but modified the barrier system by placing patients into individual cubicles (four walls, with open top) within a large multi-patient room [Garner 1996, Jackson and Lynch 1985]. It is important to note that neither of these systems placed emphasis upon airborne isolation. This near-total focus on contact transmission, to include droplet spread, was largely influenced by the writings of Charles Chapin, a Rhode Island public health official, who wrote:

> "*Bacteriology teaches that former ideas in regard to the manner in which diseases may be airborne are entirely erroneous; that most diseases are not likely to be dust-borne, and that they are spray-borne only for two or three feet, a phenomenon which after all resembles contact infection more than it does aerial infection as ordinarily understood.*" [Chapin 1912]
>
> and
>
> *"We are warranted then, in discarding it* [airborne infection] *as a working hypothesis and devoting our chief attention to the prevention of contact infection."* [Chapin 1912]

Chapin's position on the limited range of infection transmission by droplets was largely driven by the work of microbiologist Carl Flugge, to whom Chapin gives credit for the discovery of droplet infection. Flugge (as reported by Chapin) had concluded that infection by droplets was much more probable than infection by dust-borne agents, and he had documented the generation of droplets originating from the mouths of patients engaged in speaking, loud talking, coughing, and sneezing [Chapin 1912]. In addition, Chapin described experiments by Laschtschenko and Heymann, directed by Flugge, which exposed guinea pigs in front of coughing tuberculosis patients and found no resulting infections when the guinea pigs were held further from the source than 1 meter [Chapin 1912]. Although he had demonstrated the ability of bacteria-laden droplets to travel up to nine meters, Flugge's and subsequently Chapin's conclusion was that the spread of droplets with sufficient infective concentration to cause disease transmission was limited to within the arm's reach of the subject [Chapin 1912, Fitzgerald 2002]. Another factor to influence Chapin's position was the concern that recognition of airborne contagion could lead to the decline in other protective behaviors:

> *"Infection by air, if it does take place, as is commonly believed, is so difficult to avoid or guard against, and so universal in its action, that it discourages effort to avoid other sources of danger. If the sick room is filled with floating contagium, of what use is it to make much of an effort to guard against contact infection?"* [Chapin 1912]

Incidentally, a historical reference to note (though no causal implications are claimed) is that the worldwide influenza pandemic of 1918–1919, responsible for over 20 million deaths (approximately 0.5 million in the United States) [HHS 2004], coincided with this peak period of "airborne apathy" regarding patient isolation.

As 1925 approached, the emphasis on where to treat patients with communicable diseases began to shift from communicable disease hospitals toward general hospitals [Jackson and Lynch 1985]. With the exception of tuberculosis sanatoriums, which lagged moderately behind this trend, this transition continued over the next 25 years. The cubicle and barrier methods continued to be the means of isolation used for treating those patients diagnosed with communicable diseases.

The Development of Droplet Nuclei Theory

Perhaps the most important 20th century contributor to the issue of airborne isolation was William F. Wells, a sanitary engineer whose research at the Harvard School of Public Health (1930–1937) and later at the University of Pennsylvania Medical School's Laboratory for the Study of Airborne Infection (1937–1944) provided the droplet nuclei theory for the airborne spread of contagion. In the early 1930s, the Massachusetts Department of Public Health was investigating the speculation that stagnant water used to suppress dust in textile mills was a source of bacterial infection for the exposed workers. Wells developed an air centrifuge with which he and a student assistant, Richard Riley, successfully cultured bacteria from the air inside a textile mill. Surprisingly, samples collected outside the areas of visible suppression spray were also sources of culturable bacteria. This discovery led Wells to speculate that these airborne source particles, which he termed

"droplet nuclei," were the remaining residue following in-flight evaporation of the suppression spray droplets. After witnessing these surprising results, Wells hypothesized that droplet nuclei could also be the mechanism responsible for airborne transmission of infectious diseases such as measles and tuberculosis [Massachusetts Department of Public Health 2002]. In his 1934 publication *On Air-Borne Infection*, Wells provided the theoretical reasoning for the existence of "droplet nuclei," which could remain aloft for a considerable time and distance after the water component of an airborne droplet quickly evaporates. In almost direct repudiation of Charles Chapin, Wells wrote:

> *"It would be incorrect to conclude merely from this* [settling calculations based upon Stokes' and Newton's laws], *however, that air receiving infected droplets cannot convey such infection long distances. To do so would be to neglect a most important characteristic of liquid droplets, namely their tendency to evaporate."* [Wells 1934]

Thus, if the droplet diameter was sufficiently small that the evaporation process completes prior to falling from mouth to floor, then the droplet nuclei had the potential to spread contagion for considerable time and distance [Wells 1934]. Wells used a simplified case, depicted in Figure 2, to demonstrate the concept, showing curves of evaporation and falling time over a height of 2 meters (the approximate height of a man). For droplets whose diameters were $\geq$1 mm, the falling time was calculated with Newton's equations for gravitational settling, as the effect of air resistance was negligible for these droplets. For smaller droplets whose diameters were $\leq$0.1 mm, falling times were determined according to the particles' terminal velocities, as calculated with the Stokes drag formula to account for the air resistance upon the falling droplets [Wells 1934]. Settling times for droplets between 0.1 mm and 1.0 mm were determined by using log-linear interpolation. The falling-time calculations were generated with the assumption of saturated air, thus allowing for fixed droplet diameters throughout the fall. The evaporation times were computed from the droplet evaporation data published in 1932 by Whytlaw-Gray and Patterson in *Smoke: A Study of Aerial Disperse Systems* (as cited by Wells) [Wells 1934]. The assumption of pure water droplets in unsaturated air was used for the evaporation calculations; thus the theoretical droplets were capable of complete evaporation. When plotted onto the same graph, the curves were similar yet with opposite trends. The point where the two curves intersected was the smallest droplet size that actually reaches the ground (Figure 2). On the basis of these calculations, Wells determined:

> "*Somewhere between .1 and .2 mm lies the droplet size which identifies droplets of mouth spray that reach the ground within the life of the droplet, as against droplets that evaporate and remain in the air as droplet nuclei with attached infection*" [Wells 1934].

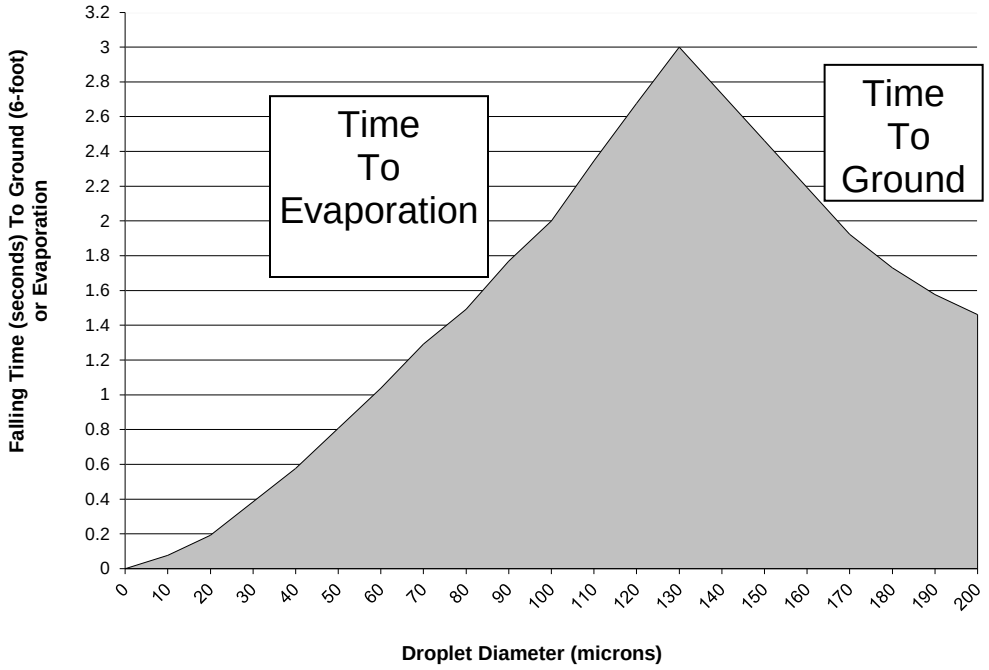


Figure 2. Falling times and evaporation times of water droplets in air. (Graphic created from data published in *Epidemiologic Basis of Tuberculosis Control* [Rieder et al. 1999].)

To account for the real-life scenario in which the droplet's diameter decreases due to evaporation, Wells proposed to evaluate mouth spray under the following parameters: (1) that the aerosol's falling velocity was directly proportional to its surface area (i.e., the falling velocity was driven by Stokes' law); and (2) the rate of change of the surface (the evaporation rate) was constant (as would be the case for an environment with constant temperature and humidity). In equation form, this is:

Falling velocity: $\frac{dh}{dt} = k \cdot S$

Evaporation rate: $\frac{dS}{dt} = c$

Combining equations: $\frac{dh}{dS} = \frac{k}{c} \cdot S$

After integration: $h = 0.5 \cdot \left(\frac{k}{c}\right) \cdot S^2$

Define a new constant: $K = \frac{k}{2c}$, then $h = K \cdot S^2$

Since $S = \pi \cdot D^2$,

define another new constant $K' = (\pi)^2 \cdot K$, then $h = K' \cdot D^4$

where:

h = height,

t = time

S = droplet surface area

D = droplet diameter

c, k, K, and K' are constants as defined above

Thus, Wells concluded that for the described scenario of very small droplets and constant humidity and pressure, "The distance a droplet will fall before ceasing to be a droplet is therefore proportional to the square of the surface or the fourth power of the diameter." [Wells 1934]

After accounting for environmental factors such as temperature and humidity as well as the fact that droplets from humans will contain dissolved substances which could alter the evaporation rate, Wells rendered a conclusion regarding the mechanisms of infection transmission through air. His conclusion directly contradicted the earlier statements by Chapin and is still generally (except for droplet size references) accepted in the 21st century. Wells concluded that transmission of infection through the air may take one of two forms: (1) droplet infection, as it applies to droplets larger than 100 micrometers (μm) in diameter, which are rapidly removed from the air by gravity, before evaporation and within a short distance of the patient, and (2) airborne infection, which deals with infected droplet nuclei, derived directly from droplets less than 100 μm in diameter, which because of their buoyancy have the potential to remain suspended in the air for considerable distances and time [Wells 1934].

Wells' droplet nuclei hypothesis is arguably the most influential contribution to the science of airborne disease transfer and efforts to isolate the airborne route of transmission. The hypothesis, which was later proven and demonstrated as a causative route of disease transfer, gave rise to a flurry of research over the next 30 years, much of which centered on tuberculosis [Wells and Brown 1936; Ratcliffe and Wells 1948; Wells and Ratcliffe 1948; Wells 1955; DeJong and Winkler 1964; Riley 2001]. These studies had both successes and failures, as the droplet nuclei under research were invisible and easily dispersed and thus difficult to trace environmentally and control with certainty.

The discovery of ultraviolet radiation (UV) as a form of airborne "disinfectant" allowed the development of numerous studies between irradiated environments and nonirradiated environments in an attempt to prove the airborne transmission route as well as the protective effects of UV. However, in the case of naturally occurring diseases such as measles, influenza, chickenpox, etc., control of the airborne

environment at a school or workplace was generally insufficient if the subjects were later exposed in noncontrolled environments. Thus, Wells and the other researchers of the time who pursued this investigational approach had mixed results. After successfully demonstration of UV's protective effect against airborne transmission of measles in selected Philadelphia grade schools, similar studies in New York, London, and a Naval training station bore mixed-to-negative results, possibly due to significant periods of subject exposure to nonirradiated atmospheres [Riley 1980]. The ability to completely control the air to which people were exposed was proving to be a difficult task, and the failure to halt the spread of contagious disease through the use of UV was seen as proof that the droplet nuclei theory was a fallacy. Despite the popularity of airborne contagion theory in the 1930s and 1940s, the failure to conclusively prove that droplet nuclei were a major epidemiologic route of airborne contagion redirected the pendulum of popular belief back to the nonairborne advocates by the middle of the 20th century.

Droplet Nuclei: From Theory to Human Contagion

In 1954, the opportunity arose to demonstrate the presence of disease that resulted from airborne contagion, as opposed to previous efforts that had attempted to prevent disease through total elimination of airborne contagion (via UV). This research effort, which focused on airborne contagion as it applied to tuberculosis, occurred at the Veterans Administration (VA) Hospital in Baltimore, MD. After Wells had demonstrated that rabbits could be infected with bovine tuberculosis via lab-generated droplet nuclei, the next, obvious step was to determine specifically if tuberculosis could be transmitted via human-generated droplet nuclei. Richard Riley, who by then was a professor at neighboring Johns Hopkins University, was the principal investigator. Wells and his assistant, Cretyl Mills, were the nucleus of the research team. The research plan sought to determine whether guinea pigs, exposed to air transferred from a 6-bed tuberculosis ward, would become infected under conditions that precluded causes other than droplet nuclei. (Wells was familiar with work from over sixty years prior at Brompton Hospital, in England, where guinea pigs placed in a ventilation shaft had contracted tuberculosis.) The first trial covered a two-year period. The guinea pigs were skin tested for tuberculosis infection each month, and on an average, three guinea pigs per month were discovered to be stricken with tuberculosis. This was the same infection rate that Wells had anticipated [Riley 2001]. Subsequent animal lung autopsies revealed a single peripheral focus of tuberculosis, resulting from the apparent inhalation of just a single infectious droplet nucleus. Critics, however, claimed that the cases could have originated from the food, water, or perhaps contact. The research study had failed to include a control group, which could disprove routes of exposure other than the aerial ones. The researchers repeated the study, this time with a control group of 150 guinea pigs with identical exposure conditions, except that the transfer air to their exposure cage was disinfected with UV. After an additional two years of data collection, the research effort was again successful in demonstrating transfer of tuberculosis disease in the subject group of guinea pigs; only this time, use of the control group, with no infections of tuberculosis, verified the apparent source of infection as droplet nuclei in the nonirradiated transfer air [Riley et al. 1959].

Another landmark study in the understanding of airborne disease transmission was the mid-1960s experiments by Loudin and Roberts that documented generation rates for the droplets and droplet nuclei produced by means of talking and coughing. The investigators demonstrated that a single cough generated about the same number of droplets as thirty seconds of talking and the same number of airborne droplet nuclei as five minutes of talking. Perhaps even more important was the observation that almost half (49 percent) of the cough-generated droplet nuclei remained suspended more than thirty minutes following their generation, as opposed to only 6 percent of the talk-generated droplet nuclei over the same time period. These findings led the investigators to the conclusion that coughing was an important mechanism in the production of droplet nuclei with infective potential [Loudin and Roberts 1966]. As will be discussed later in this document, these findings are still relevant to modern day approaches for the handling of patients with potentially infectious diseases, especially those who are undergoing cough-inducing procedures.

Finally, it was not a research discovery but two nosocomial outbreaks of smallpox that arguably proved the applicability of airborne contagion theory to human health. Both outbreaks occurred in West Germany, the first at Monschau in 1962 and the second in Meschede in 1970. The World Health Organization (WHO) concluded that both of these outbreaks “seem certainly to have been airborne”[Fenner et al. 1988]. The Meschede outbreak is probably the most studied and thus the better known of the two. In this outbreak, an electrician returning from a trip to Pakistan was hospitalized 10 days after his return, with a feverish illness suspected to be typhoid. He was confined to his room and developed a rash after three days. After an additional two days, he was diagnosed with smallpox and consequently transferred to a smallpox hospital. Nineteen additional cases of smallpox subsequently occurred on all three floors of the original building in which the index patient had been treated. Of these 19 cases, 17 occurred within a single incubation period, confirming the index case as the source patient. It is also significant to note that several of these cases developed at a significant distance from the index patient [Fenner et al. 1988]. Figure 3 is a schematic showing the distribution of cases throughout the hospital. The figure also shows the upward dispersion observed during smoke tests conducted by WHO researchers following the outbreak [CDC 2003c].

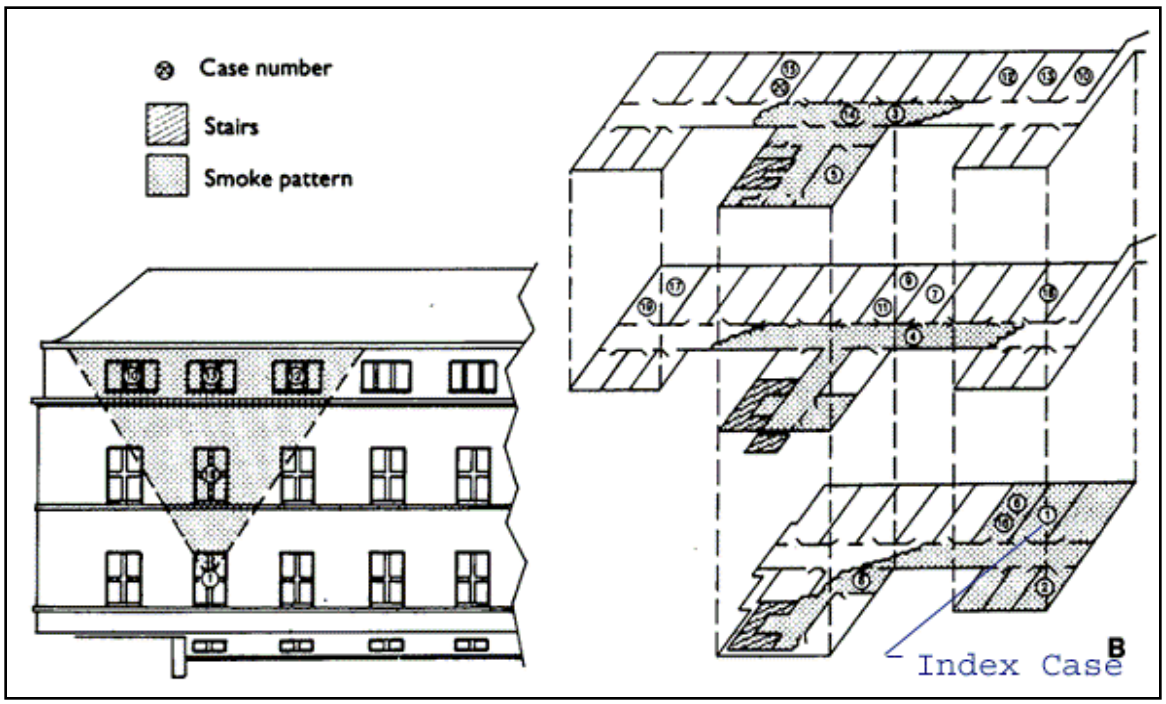


Figure 3. Schematic detailing airborne transmission of smallpox at a hospital in Meschede, Germany (1970), and the similar dispersion of tracer smoke tests conducted later by the WHO [graphic: CDC].

The Evolution of Standardized Hospital Isolation Criteria

In 1951, the American Public Health Association (APHA) held a large meeting to develop policy recommendations for the care of patients with communicable disease. Fueled by at least one U.S. study which indicated infectious disease hospitals had personnel and facilities that were inferior to general hospitals, the APHA recommended that communicable disease patients be treated at home, unless seriously ill, in which case they should be treated in general hospitals [Jackson and Lynch 1985]. Thus, as the 1950s progressed and infection control policies and procedures improved, the isolation hospitals were dwindling in number (with the exception of tuberculosis sanatoriums) and patients with communicable diseases were treated in general hospitals or at home. During this same era, nosocomial outbreaks of staphylococcal infections occurred in several U.S. hospitals, and some facilities began to place infectious patients into specially designed isolation rooms [Bjerke 2002; Whitehouse et al. 1998]. These outbreaks led the Communicable Diseases Center (the predecessor to the Centers for Disease Control and Prevention [CDC]) to sponsor a meeting on nosocomial transmissions of staphylococcal infections in 1958. During that same year, the American Hospital Association (AHA) published recommendations on the prevention and control of *Staphylococcus* infections. For the first time, the AHA recommended that (1) infection control committees be established in each hospital; (2) a system for reporting infections among patients and personnel be developed; (3) hospitals distinguish between infections acquired within the hospital versus outside of the hospital; (4) aseptic practices for most hospital settings be evaluated; and (5) the

use of antibiotics and adrenocorticosteroids be reduced as much as medically realistic [Jackson and Lynch 1985].

As the mid-1960s progressed and knowledge of tuberculosis and its believed mechanisms of spread became more established, the tuberculosis sanatoriums also began to close and tuberculosis patients were treated in special rooms or wards at general hospitals or even at home [Garner 1996]. A formalized approach to hospital-associated infections was begun by the AHA in 1962 with the publication of its first monograph on hospital infections, a significant portion of which was devoted to modes of transmission and methods of control [Larson 1997]. In addition, in 1969, the Joint Commission for the Accreditation of Hospitals (JCAH) published its first accrediting standards, which required, among other things, the establishment of an infection control committee and availability of patient isolation facilities [JCAH 1969].

The CDC Weighs In

In recognizing that the lack of a consistent prevention system contributed to the problem of nosocomial infections, the CDC's Hospital Infections Program (HIP) published *Isolation Techniques for Use in Hospitals* in 1970 [National Communicable Disease Center 1970]. This document introduced a category system of isolation within seven color-coded categories: S*trict Isolation*, *Respiratory Isolation*, *Protective Isolation*, *Enteric Precautions, Wound and Skin Precautions, Discharge Precautions,* and *Blood Precautions*. Diseases were categorized according to the epidemiological evidence of transmission. Isolation guidance was category specific and could be easily recognized through the use of color-coded placards and patient charts. However, because the precautions for a particular disease category were based upon the worst offender (i.e., the most infectious) in that category, the system led to over-isolation (and added expense) for the category's lesser offenders. The focus of CDC's initial guidance was upon general hospitals. This focus was extended to include small community hospitals when the guidance was revised in 1975 [CDC 1975]. In addition, the 1975 revision included guidance and recommendations regarding the avoidance of contaminations via "sharps" (i.e., needles, scalpels, scissors, broken glass), and it introduced a new appendix with a disease list that provided additional information on precautions and data for the color cards. In 1978, CDC's guidance was updated once again to address newly identified syndromes.

The first major change/update to the CDC guidance came in 1983. A title change to *CDC Guideline for Isolation Precautions in Hospitals* [Garner and Simmons 1983] placed the document into the vague category of being nonregulatory yet offering federal guidance that was often adopted by various jurisdictions as state-of-the-art practice. One of the most obvious changes in the 1983 guidelines was the empowerment of hospitals and individual healthcare providers to make decisions regarding the isolation practices required for their patients. Hospital infection control committees were allowed to choose from a revised category system, a new disease-specific system, or some adaptation of the guidelines to develop a unique system specific to the patient needs at their particular hospitals [Garner and Simmons 1983]. In addition, in assigning a patient to isolation, individual

healthcare providers were empowered to alter the precautions according to specific factors (e.g., the patient's age or mental status) and to make decisions regarding their need for personal protective equipment on the basis of their anticipation of exposure to infectious material.

Within the 1983 category-specific approach, the CDC guidelines offered seven revised categories of isolation. After elimination of the *Protective Isolation* category because of study findings that challenged its necessity or efficacy, the remaining categories were *Strict Isolation*, *Contact Isolation*, *Respiratory Isolation*, *TB Isolation*, *Enteric Precautions*, *Drainage/Secretion Precautions*, and *Blood and Body Fluid Precautions*. For those hospitals choosing the disease-specific approach, each disease was listed with its epidemiology of transmission, and only those precautions required to interrupt the identified transmission routes were required. Although it was hoped that the reductions in over-isolation would result in cost savings, the increased combinations of possible precautions allowed under this approach required more documentation and attention to detail than the previous, color-coded category system. Knowledge gaps and competing theories about the epidemiology of transmission of certain diseases brought about disagreement and controversy. This was especially so for the pendulum of opinions regarding diseases of close-proximity droplet versus airborne-droplet nuclei transmission [Garner 1996]. Airborne isolation and respiratory protection were expensive, and committee members may have been hesitant to recommend these precautions unless absolutely positive that they were warranted.

Just as in the earlier version, several revisions to CDC's 1983 guidance document occurred as new data and disease awareness evolved. In 1987 the concept of *Universal Precautions* (UP) was adopted, largely due to the epidemic of human immunodeficiency virus (HIV) infection and the challenges of treating HIV-infected patients. These precautions introduced the approach of treating every patient as if he or she had a disease requiring blood and body substance precautions. A competing concept, *Body Substance Isolation* (BSI), was published later that same year by infection control personnel in Washington and California [Lynch et al. 1987]. Similar to UP, BSI precautions were applied to all patients and were based on the assumption that all moist and potentially infectious body substances were infectious. In addition, BSI incorporated a stop-sign alert to redirect persons about to enter a potentially airborne infectious area; the sign directed them to the nurses' station for determination of necessary respiratory protection.

OSHA Proposes Bloodborne Pathogens Regulation

As concerns increased regarding the transmission of HIV and hepatitis B virus (HBV) within healthcare and health research settings, the Occupational Safety and Health Administration (OSHA) proposed a rule in 1989 regarding occupational exposures to bloodborne pathogens (BBP) [OSHA 1989]. The proposed rule was based upon CDC's UP approach; however, it introduced new terms such as "visibly bloody" as a means of identifying potentially hazardous body substances. Within the healthcare community, the proposed rule received criticism for its disproportionate focus on worker protection (as opposed to patient protection), for its adoption of UP without sufficient research data proving its efficacy, and for the

increased financial burden to the industry [Garner 1996]. Despite these objections, the rule was finalized in December 1991 and became effective in March of the following year [56 Fed. Reg. 1030 (1991)]. Although the rule contained instructions applicable to direct contact, secondary contact, and droplet spread, there were no specific instructions regarding airborne precautions for healthcare workers. At the same time, the rule required airborne precautions for institutions engaged in HIV or HBV research or production.

CDC Isolation Precautions for Control of Tuberculosis

The CDC has also addressed the issue of patient isolation precautions in some disease-specific guidance publications. In regards to airborne transmission precautions, the most influential of these were the CDC publications on prevention of tuberculosis transmission within healthcare settings. The earliest CDC guidance document for tuberculosis was published in 1982, followed by a joint publication with the American Thoracic Society in early 1983 [CDC 1982; ATS 1983]. Although shared-air volumes with infectious patients were acknowledged as a key risk factor, these publications placed an emphasis on treatment of tuberculosis patients at home, unless other medical conditions warranted their hospitalization. Isolation itself was insufficient justification for hospitalization. In those cases where hospitalization was warranted, "appropriate infection control practices" were encouraged (yet not delineated) to protect healthcare workers and other patients from infection.

By 1990, increased concerns regarding nosocomial transmissions of multi-drug-resistant tuberculosis led the CDC to update its recommended precautions for preventing tuberculosis transmission within hospital settings. This was especially relevant to healthcare settings that provided treatment to individuals infected with HIV. Within these settings, both patients and healthcare workers were increasingly becoming infected through nosocomial transmissions [Jarvis et al. 1995]. The updated document, titled *Guidelines for Preventing the Transmission of Tuberculosis in Health-Care Settings, with Special Focus on HIV-Related Issues,* completely embraced the concept of airborne precautions, with special emphasis on (1) placing patients in private, negative-pressure isolation rooms (NPIR) with a minimum mechanical ventilation rate of six air changes per hour (ACH)[1] [ASHRAE 1991], two of which had to be with outside air; and (2) use of engineered source control during high-risk procedures (e.g., specialized booths for sputum induction procedures), to capture and remove infectious droplet nuclei before they could be released into room air. The use of germicidal UV lamps (wavelengths = 100–290 nm) and High-Efficiency Particulate Air (HEPA) filtration systems was also discussed as a way of reducing airborne contamination within general-use hospital areas (emergency rooms, waiting areas). By definition, HEPA filters have a minimum particle-capture efficiency of 99.97 percent when challenged with a test aerosol of 0.3-μm diameter [USDOE 1997]. The 1990 guidelines also advised that surgical masks may be

[1] Air changes per hour (ACH) is a term used to describe a room or zone's ventilation flow rate. It is determined by measuring the room airflow in volume units per hour and then dividing that value by the room or zone's space volume (using consistent volume units). The term does not consider air-mixing efficiency.

insufficient respiratory protection to protect healthcare workers in some settings, and they identified “disposable respirators” as a better alternative.

In 1993, an updated draft of CDC’s 1990 tuberculosis guidelines was released for public comment. Following the review and comment period, the guidelines were modified and published in 1994 with the shortened title, *Guidelines for Preventing the Transmission of Tuberculosis in Health-Care Settings* [CDC 1994]. This draft was largely motivated by the following concerns: (1) the rising incidence of nosocomial transmission of multi-drug-resistant tuberculosis; (2) a rising opinion that prior respiratory protection guidance had been insufficient; and (3) early research indications whose results endorsed the 1990 guidelines *if* the recommended ventilation and source controls were strictly followed and used in tandem with respirators capable of filtering 1-micron (µm) particles with at least 95 percent efficiency [Jarvis et al. 1995]. Driven by these factors and roughly 2700 public review comments, the guidelines were finalized in 1994 with a stronger emphasis on the hierarchy of controls to prevent transmission of tuberculosis and delineated performance criteria for respiratory protection for those situations where engineering and administrative controls were insufficient to control the hazard [Jarvis et al. 1995]. Specific changes pertinent to the design and operation of airborne isolation rooms included addition of a special supplement to the guidelines, entirely focused upon the design, operating, and testing parameters associated with the engineering control of aerosols with infectious potential. Although many of the individual concepts remained the same (i.e., source control, dilution ventilation, HEPA augmentation), the level of explanation for each of these dramatically increased. The revisions included these changes:

- Increased minimum ventilation rates within negative-pressure isolation rooms, to 12 ACH for new and remodeled rooms; for existing rooms, an increase to a minimum of 12 ACH, if possible, or augmentation with recirculating HEPA-filtered systems.
- Increased emphasis on engineering controls for source capture during aerosol-producing treatment activities (both enclosing and exterior methods of local exhaust were described).
- Increased emphasis on ventilation delivery within isolation rooms in order to maximize mixing and reduce likelihood of ventilation dead spots or short-circuiting.
- Recommendation of a minimum pressure differential of 0.001 inches of water across the perimeter of the negative-pressure isolation room in order to establish necessarily consistent airflow into it. (Note: This was potentially the weakest of the recommendations as noted by many of those who commented, arguing that such a small differential could be easily reversed under normal operating conditions.)
- Monitoring frequency for negative pressure and airflow into isolation rooms increased from “frequently” to daily.

The Hospital Infection Control Practices Advisory Committee

As the 1990s began, the U.S. healthcare industry lacked consistency in its knowledge and approach to infection control practices. Despite similar concepts and terms, there was inconsistency in their interpretation and uncertainty over which precautions were applicable to which body substances. Consequently, CDC's infection control guidance evolved further [Garner 1996]. In 1991, after considerable feedback from infection control practitioners that showed an overhaul of the 1987 guidance was in order, the CDC requested that the U.S. Department of Health and Human Services (HHS) Secretary issue a charter for a *Hospital Infection Control Practices Advisory Committee* (HICPAC). This committee would assist CDC in the development of guidance for the prevention of nosocomial infections [O'Rourke 1995]. The charter established a 12-person committee of individuals with varying infection control backgrounds and interests to serve as technical advisors to CDC's Hospital Infections Program. The charter established that HICPAC members would be appointed to 4-year terms by the HHS Secretary. The result of this new partnership was a revised draft of CDC's hospital isolation guidance released in 1994 and finalized in 1996 [Garner 1996]. The updated document consolidated and simplified the pre-existing infection control practices while espousing goals to be epidemiologically sound,[2] simple, and user-friendly; to introduce new terms to alleviate the confusion with previous infection control; and to allow modifications of the guidance according to individual hospitals' needs and circumstances. To this effect, the new guidelines introduced two tiers of isolation precautions. In the first tier were those precautions designated for all patients, regardless of their presumed or confirmed diagnosis. These were termed *Standard Precautions* and were a synthesis of the features in UP and BSI precautions (handwashing, gloves, eye protection, etc.). The second tier introduced three *Transmission-based Precautions*; these were applicable only to those patients known or suspected to be infected with highly transmissible or epidemiologically important pathogens for which one or more precautions, beyond Standard Precautions, were necessary to prevent nosocomial transmissions. The three transmission-based precautions were *Contact Precautions* (applicable to infections transmissible via direct or indirect contact), *Droplet Precautions* (applicable to infections transmissible via large [>5 μm] particle droplets), and *Airborne Precautions* (applicable to infections transmissible via small [≤5 μm] airborne droplet nuclei or dust particles containing the infectious agent) [Garner 1996]. Interestingly, the zone of concern for Droplet Precautions was limited to within only three feet of the patient, an apparent carryover from the writings of Chapin and Flugge, which had been perpetually cross-referenced throughout the 20th century. The guidance for patients requiring Airborne Precautions included private rooms, monitored negative pressure, 6 to 12 ACH ventilation, and discharge of room exhaust to the outdoors or high-efficiency filtration prior to recirculation to other areas of the hospital.

In June 2004, CDC and HICPAC released for public comment a draft update of their 1996 hospital isolation guidelines, *Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings* [Siegel 2004]. The five-

[2] Note: The reference to epidemiologic justification reflected the ongoing debate between research scientists and the medical community over airborne contagion issues.

part draft guideline, which increased in number of pages by a factor of four over the 1996 two-part version, expanded and updated the guidelines to account for changing trends in the healthcare industry. These included (1) transitions in healthcare settings from hospital environments to other healthcare settings (ambulatory, specialty care, home care, long-term care, etc.); (2) the emergence of new pathogens, multi-drug-resistant variations of old pathogens, new therapies, and the threat of biowarfare; and (3) new research findings regarding various healthcare isolation practices. The 2004 draft described two tiers of precautions, identified as *Standard Precautions* and *Expanded Precautions* (a resynthesis of the former transmission-based precautions). In addition to reaffirming the concept of Standard Precautions, the draft expanded it to include "Respiratory Hygiene/Cough Etiquette," which was intended to prevent potential disease transmissions beginning from the patient's first point of contact with the healthcare setting. This recommendation arose out of the global outbreak of Severe Acute Respiratory Syndrome (SARS), a viral respiratory illness caused by a coronavirus now identified as SARS-associated coronavirus (SARS-CoV) [CDC 2004a]. The SARS outbreak began in Asia in February 2003 and spread to over two dozen countries on four continents, eventually infecting as many as 8,098 persons and causing 774 deaths, according to the WHO. Lastly, the 2004 draft resurrected the concept of protective isolation with the description of Protective Environment patient rooms, designed to decrease the risk of life-threatening fungal infections in immunocompromised patients. In June 2007, the 2004 draft isolation guidelines were finalized as a four-part document, without a previous discussion on performance indicators and with an added appendix that included a large tabular listing of the type and duration of precautions recommended for selected infections and conditions [Siegel et al. 2007].

Pathogens of Interest for Airborne Isolation

Pathogens are defined as any agents that cause disease [Webster's II New Riverside University Dictionary 1988]. Those pathogens that affect the respiratory tract are termed respiratory pathogens and can be classified into three categories: bacteria, fungi, and viruses. Of these, the fungi and some of the bacteria are spore-forming, and it is the spores, not the secretions or droplets from a sick patient, which have the potential for airborne transfer. Thus, airborne infection isolation (AII) is generally not a concern for patients with these infections. When patients are externally contaminated with spore-containing material (e.g., following a bioterrorism incident) or when patients require protective environments, the ability to control exposure to such spores is desired. In addition to the protective benefits provided by patient decontamination, spores are comparatively much larger than bacteria or viruses and are thus much easier to filter out of the air (Figure 4) [Hinds 1982]. Consequently, the more challenging scenarios are generally those requiring protection from airborne bacteria or viruses.

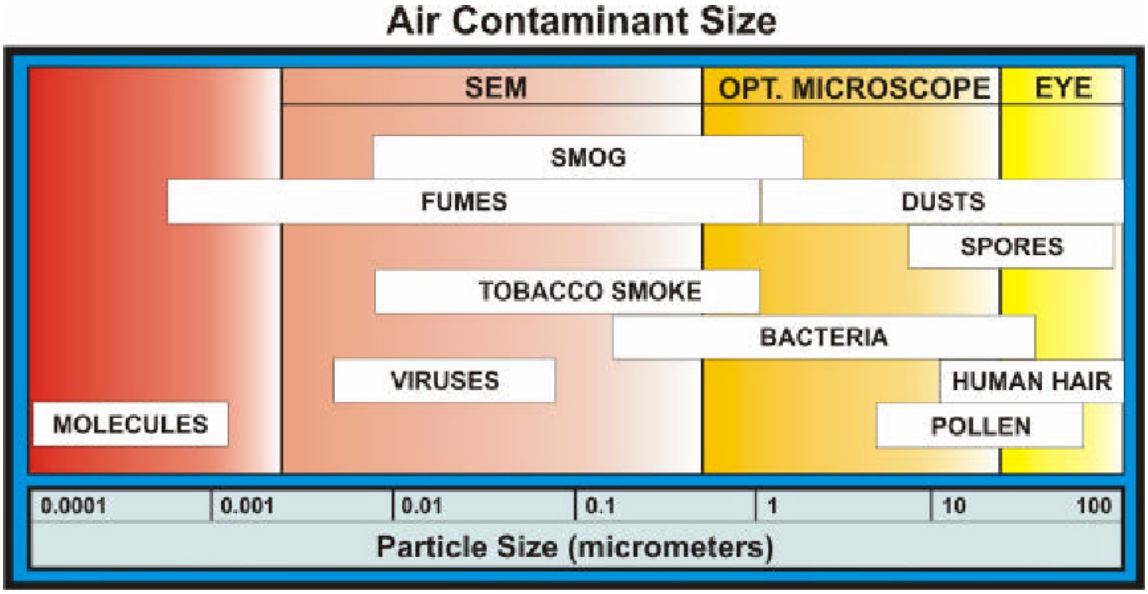


Figure 4. Common air contaminants and their relative sizes (graphic: CDC/NIOSH).

Another way to consider airborne pathogens is in terms of whether they are communicable (i.e., contagious) or noncommunicable. Communicable diseases generally originate from other humans, though sometimes from animals, whereas noncommunicable diseases come mainly from the environment. However, in the hospital environment, immunosuppressed patients can be susceptible to microbes from either humans or the environment that normally would not result in disease. Hence, for the healthcare environment, airborne pathogens can be placed into one of three classes: (1) communicable, (2) noncommunicable, and (3) primarily nosocomial [Kowalski and Bahnfleth 1998]. If the need arises to establish surge capacity for expedient patient isolation, control of communicable airborne pathogens would require infection isolation techniques (negative pressure). A surge of potentially immunosuppressed patients (such as what might occur following widescale exposure to radioactive material) would necessitate protective isolation (positive pressure) from airborne pathogens that fall into the noncommunicable and primarily nosocomial classes [Oak Ridge Institute for Science and Education 2004].

Appendix A of CDC's 2007 *Guidelines for Isolation Precautions in Hospitals* includes an updated list of selected infections and diseases and the associated HICPAC precautions for handling patients with these diseases. In the 1996 version of the same guidelines, only 4 of 200 conditions listed were associated with airborne precautions [Garner 1996]. These included varicella (chicken pox), pulmonary tuberculosis, measles, and herpes zoster (varicella-zoster/shingles). Since publication of the 1996 guidelines, public health events have added monkey pox (until a smallpox diagnosis can be definitely eliminated) and SARS to the list of diseases for which airborne precautions are recommended [Siegel et al. 2007; CDC 2004; CDC 2007]. In addition to known diseases, emerging diseases such as the H5N1 or H1N1 emerging influenza strains may also require various applications of airborne isolation precautions [CDC 2004].

Lastly, among the Category A bioterrorism agents, defined as agents which can be easily disseminated or transmitted person to person, can cause high mortality with potential for major public health impact, might cause public panic and social disruption, or require special action for public health preparedness) are a handful that could result in a surge requirement for AII [Nolte et al. 2004]. The Category A agents include *Variola major* (smallpox); *Bacillus anthracis* (anthrax); *Yersinia pestis* (plague); *Clostridium botulinum* toxin (botulism); *Francisella tularensis* (tularemia); filoviruses (Ebola hemorrhagic fever, Marburg hemorrhagic fever); and arenaviruses (Lassa [fever], Junin [Argentine hemorrhagic fever], and related viruses). Of these, only pneumonic plague, smallpox, filoviruses, and arenaviruses are indicators for airborne precautions [Nolte et al. 2004; Khan et al. 2000].

Engineering Design Standards for Hospital Isolation

In 1946, Congress passed the Hospital Survey and Construction Act (a.k.a. Hill-Burton Act), which established a major hospital facility construction and renovation program and was sponsored by Senators Lister Hill and Harold Burton [Public Law 79-725, 60 Stat.1040]. In 1947, the first *General Standards* (for hospital design) were published in the Federal Register as part of the implementation of Hill-Burton [American Institute of Architects 1987]. These standards, which were regularly updated by the federal government, required hospitals that received federal funds via Hill-Burton to adhere to certain design, equipment, and operational standards. In 1973, the standards were retitled as *Minimum Requirements of Construction and Equipment for Hospital and Medical Facilities*. Maintenance, updates, and publication of the standard were accomplished by the Department of Health, Education, and Welfare (DHEW) and subsequently the Department of Health and Human Services (HHS). Thus, the standard fulfilled congressional mandates to prescribe by regulation the minimum standards for construction, renovation, and equipment for hospital projects funded under certain federal grant and loan provisions. As the act providing the specific federal funding provisions expired, the regulatory aspect of the standard became moot, and in 1984 the publication was retitled as *Guidelines for Construction and Equipment of Hospital and Medical Facilities* to reflect the nonregulatory status [HHS 1984].

In regards to the design and operation of hospital isolation rooms, the 1984 hospital guidelines were consistent with the criteria published in the 1976 and 1979 versions of its predecessor, *Minimum Requirements of Construction and Equipment for Hospital and Medical Facilities* [U.S. Bureau of Health Facilities Financing, Compliance, and Conversion 1976, 1979]. Namely, these requirements were for

- negative pressure (magnitude not specified)
- total airflow of 6 ACH (the 1974 and 1979 documents also required 2 ACH of outdoor air)
- 100 percent exhaust to outdoors
- no recirculating room-conditioning units
- positive-pressure anterooms with 10 ACH, as enhanced protection.

The 1984 guidelines were the last to be published by the federal government. Despite the expiration of regulatory authorization, the regulatory language remained, as the guidelines were used by HHS as evaluation criteria for hospital mortgage insurance applicants and by the Indian Health Service for hospital construction projects. In addition, other groups or jurisdictions such as JCAH (which in 1987 became known as the Joint Commission on Accreditation of Healthcare Organizations, or JCAHO) and individual state licensure agencies were welcome to use the criteria. Beginning with the 1987 edition, maintenance and publication of the guidelines was handled by the American Institute of Architects (AIA) Committee on Architecture for Health. The change in publishers did not have an overwhelming impact upon the philosophy of the guidelines, however, as 12 of 36 committee members were from the U.S. Public Health Service (USPHS) and several nonmember contributors from USPHS were acknowledged in the 1987 edition. Once again, the design criteria for hospital isolation rooms were consistent and did not vary from the 1984 edition [American Institute of Architects 1987].

The AIA used the occasion of the 1992–1993 edition of the guidelines to launch its first significant update. Although the general format and content of the 1992–1993 edition followed that of its 1987 predecessor, the new edition added new material to account for developing healthcare trends, while updating and clarifying the intent of sections carried over from prior editions [American Institute of Architects 1993]. Five new sections were added, describing minimum standards for specialized services within general hospitals as well as dedicated treatment facilities such as birthing centers. For new construction, regular patient rooms were limited to a maximum of two patients and central ventilation filtration systems were increased from one filtration bed to two, with the highest filtration efficiency increasing from 80 to 90 percent (Standard 52-1976, “Dust Spot Efficiency Test Method,” published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE]). Patient isolation was an important focus for the 1992–1993 guidelines as well. The term *Isolation Room* was replaced by *Infectious Isolation Rooms* and *Protective Isolation Rooms*, reflecting negative-pressure and positive-pressure isolation rooms, respectively.

While trying to maintain a 3- to 4-year renewal schedule, the AIA has released three additional updates to the hospital design guidelines, namely, the 1996–1997 *Guidelines for the Design and Construction of Hospital and Healthcare Facilities,* the 2001 edition of the same title, and the 2006 edition, *Guidelines for the Design and Construction of Healthcare Facilities*. The 2006 edition incorporated a major reorganization of the guidelines in an effort to improve the format, readability, and indexing of the document and make it a more useful and user-friendly tool [American Institute of Architects et al. 2006]. A summary of AIA’s ventilation guidance for hospital isolation rooms (under various titles), as prescribed in the multiple editions of the hospital design guidelines since 1987, is shown in Table 1. These values apply to newly remodeled or constructed rooms; existing isolation rooms were allowed to remain at the designed ventilation rate applicable at the time of their construction or latest remodel.

In the 1987 and 1992–1993 editions of the guidelines, the minimum ratio of infectious isolation rooms (single patient) to acute patient beds was 1:30, with all

fractions rounded up. No minimum number of protective isolation rooms was prescribed. Beginning with the 1996–1997 edition, the minimum number of airborne infection isolation (slight terminology change) rooms was changed to simply one, with any additional bed requirements (infection isolation or protective isolation) to be determined on the basis of an Infection Control Risk Assessment (ICRA) of the needs of the specific community and the patient population served. This recommendation continued in both the 2001 and 2006 editions; however, the 2006 edition also included, for the first time, advisory language (as an Appendix) regarding surge capacity in preparation for potential highly infectious emergencies. This language encourages hospitals to have the capacity to handle a surge of up to ten patients or a fourfold increase above the current emergency department capacity for such patients. One quote of interest from this appendix states, "If 100 percent of exhaust (from the surge isolation area) cannot be achieved, appropriate proven technology should be utilized to reduce airborne particles by >95 percent." [American Institute of Architects et al. 2006]

Table 1. Ventilation requirements for variously termed isolation rooms (remodeled or new construction), as prescribed by American Institute of Architects guidelines (1987–2001) [American Institute of Architects 1987, 1993, 1996, 2001].

Type of Room (Edition)	Air Movement	Minimum Outdoor Air (ACH)[1]	Minimum Supply Air (ACH)[1]	100% Exhaust Outdoors?	Anteroom Required / Optional	Anteroom Air Movement
Isolation (1987)	In[2]	---	6	Yes	Optional	Out
Infectious Isolation (1992–1993)	In	1	6	Yes	Optional[6]	In/Out[3]
Protective[2] Isolation (1992–1993)	Out	1	6	---	Optional[6]	In/Out[3]
Airborne Infection Isolation (1996–1997)	In	2	12	Yes[5]	Optional	In/Out[3]
Protective[4] Environment (1996–1997)	Out	2	12	---	Optional	In/Out[3]
Airborne Infection Isolation (2001)	In	2	12	Yes[7]	Optional[8]	In/Out[3,8]
Protective[4] Environment (2001)	Out	2	12	---	Optional[8]	In/Out[3,8]

Type of Room (Edition)	Air Movement	Minimum Outdoor Air (ACH)[1]	Minimum Supply Air (ACH)[1]	100% Exhaust Outdoors?	Anteroom Required / Optional	Anteroom Air Movement
Airborne Infection Isolation (2006)	In	2	12	Yes[7]	Optional[8]	In/Out[8, 9]
Protective[4] Environment (2001)	Out	2	12	---	Optional[8]	In/Out[8, 9]

1. Air changes per hour (ACH) is a term used to describe a room or zone's ventilation flow rate. It is determined by measuring the room airflow in volume units per hour and then dividing that value by the room or zone's space volume (using consistent volume units). The term does not consider air-mixing efficiency.
2. Reverse isolation with outward airflow is mentioned in the footnotes.
3. Anteroom should be negative to corridor, negative to Protective Isolation rooms, and positive to Infectious Isolation rooms.
4. Reversible airflow switches are not allowed, starting with the 1996–1997 edition.
5. Partial room recirculation via freestanding units or return air was allowed as long as air was HEPA filtered.
6. Anteroom required if program determines "strict isolation" (not defined) is necessary.
7. If not practical to exhaust outdoors, AIA allows recirculation back to main HVAC system if exclusively serving the isolation room.
8. An anteroom is required if an AII patient is also immunosuppressed. In this situation, anteroom must be negative to both corridor and patient room or positive (preferred) to both corridor and patient room.
9. The anteroom can be (1) under positive pressure to both the corridor and the patient room or (2) under negative pressure to both the corridor and the patient room. A noted advantage of option 1 is the ability to use it as a clean zone for storing and donning personal protective equipment.

ASHRAE provides design guidance specific to the mechanical design of buildings, including heating, ventilating, and air conditioning (HVAC) and exhaust ventilation systems. For hospitals and other medical facilities, this information appears in the *Healthcare Facilities* chapter (Chapter 7) of the ASHRAE handbook on *HVAC Applications,* one of four ASHRAE handbooks that are updated on a rotating basis (one handbook per year) [ASHRAE 2003a]. In regard to isolation rooms, historically there has been good agreement between the ASHRAE recommendations and those found in the AIA guidelines, as several members of the AIA guidelines committee also serve on or support the ASHRAE committee responsible for developing the *Healthcare Facilities* chapter. Discrepancies, when they have occurred, have generally been associated with the different publication cycles between the two documents or with different terminologies preferred by the two organizations. These discrepancies often required healthcare engineers to identify and follow the most stringent of the two sets of recommendations. However, at the time of the release of the 2003 edition of the *ASHRAE Applications Handbook* (June 2003), the recommendations (airflows, pressures, filtration, and design temperature) and terminologies for hospital isolation rooms (both PE and AII rooms) were identical with the 2001 AIA guidance shown above in Table 1 [American Institute of

Architects 2001; ASHRAE 2003a]. In addition, CDC's 2003 version of the *Guidelines for Environmental Infection Control in Health-Care Facilities* potentially resolved the issue of any further discrepancies by prescribing the AIA guidelines as the minimum standards whenever state or local regulations are not in place for design and construction of ventilation systems in new or renovated healthcare facilities [Sehulster et al. 2003].

In 1997, ASHRAE began developing an HVAC design manual (as opposed to a standard or guideline) for hospitals and clinics. This publication was released in 2003 as ASHRAE Special Project 91, the *HVAC Design Manual for Hospitals and Clinics* [ASHRAE 2003b]. In it, ASHRAE identifies design strategies known to meet the current standards and guidelines and in some cases offers recommendations beyond these minimum criteria, such as minimum airflow rates in anterooms or the supplemental use of UV air disinfection, which on the basis of recent research or the engineering experience of committee members were considered to be good engineering practice. In addition, the ASHRAE design manual serves as a reference to facilitate the operation and maintenance of healthcare facilities. In January 2003, ASHRAE announced its intention to develop its own healthcare ventilation standard, in collaboration with the American Society of Healthcare Engineering (ASHE) [Hermans 2003]. The subsequent standard was published by ASHRAE (co-sponsored by The American Society of Healthcare Engineering (ASHE) and approved by The American National Standards Institute (ANSI) in 2008 as ANSI/ASHRAE/ASHE Standard 170-2008, *Ventilation of Health Care Facilities* [ASHRAE 2008]. With the addition of yet another design standard, it was uncertain at first whether the new standard would contribute to consolidating the issues surrounding airborne isolation room design. This uncertainty was short-lived when Standard 170-2008 was adopted in its entirety, into *The Guidelines for Design and Construction of Health Care Facilities,* during the 2010 update to the Guidelines which is now managed and published by Facilities Guidelines Institute (FGI) instead of the AIA [FGI 2010].

Potential Lessons from Industrial Contaminant Control Theory

Airborne infection isolation and protective isolation within healthcare facilities may be thought of as a combination of traditional indoor air quality (IAQ) and industrial ventilation challenges, though perhaps outcomes due to a failure to control hold greater health implications on average. For airborne infection control, the aerosol size range of concern was defined by the CDC as $\leq$5 μm [Sehulster et al. 2003]. This was somewhat consistent with research by Riley and Wells that showed the particle size of respiratory infectious aerosols to be in the range of 1–3 μm [Riley 1974]. The important point was that both of these size ranges describe particles whose terminal settling velocities are very small, allowing room air currents to easily keep them aloft for long periods. By definition, a particle's terminal settling velocity is a constant velocity condition wherein the gravitational acceleration forces (F_g) are equally countered by the drag forces (F_d) and buoyancy forces of the air on the particle [Hinds 1982]. For a 2-μm sphere of unit density floating in air, this relationship can be shown by the following equation:

$$F_g = F_D$$

where:

$$F_g = m \times g = \rho_s \times Vol_s \times g$$

and

$$F_D = \frac{3\pi\eta V_{TS} D}{C_c}$$

where: m = mass of microsphere = density (ρ_s) × Volume (Vol_s)

ρ_s = 1.00 gm/cm^3

g = gravitational constant = 981 cm/sec^2

η = fluid (air) viscosity = 1.83 × 10^{-4} gm/cm-sec

V_{TS} = terminal settling velocity

D = microsphere diameter = 2.0 × 10^{-4} cm

C_c = Cunningham slip correction factor = 1 + (2.52 × λ)/D

where λ = mean free path = 0.066 μm (for air)

Setting $F_g = F_d$ and solving for V_{TS} yields this equation:

$$V_{TS} = \frac{\rho_s D^2 g C_c}{18\eta} = \frac{\left(1.0\frac{gm}{cm^3}\right)\left(2.0\times10^{-4}cm\right)^2\left(981\frac{cm}{\sec^2}\right)\left(1+\frac{(2.52\times0.066\mu m)}{2.0\mu m}\right)}{18\times1.83\times10^{-4}\left(\frac{gm}{cm-\sec}\right)}$$

$$V_{TS} = 1.29\times10^{-2}\left(\frac{cm}{\sec}\right)$$

Compared with typical room air currents of 20 feet per minute (fpm) (10 cm/sec) or higher velocity, it is easy to see how such particles could stay airborne for extended periods of time. Thus, their behavior will be predominantly influenced by the air currents within the room in which they are suspended and follow the room's predominant air streams [Baron and Willeke 2001].

Historical control approaches for AII rooms have used air filtration and zone pressurization as the primary means to prevent unwanted contaminant transfer between zones. Within the patient isolation room itself, the predominant control mechanism historically used to reduce airborne contaminant levels is through the introduction of large amounts of "clean" supply air in an effort to dilute existing contaminants while also exhausting air to remove the diluted aerosol from the room. The exhaust air stream is slightly oversized compared to the supply air stream, in order to produce a negative pressure gradient and consequent migration of air into the patient room from adjacent areas. As indicated in the previous discussion, design standards and guidance have historically identified the ventilation rate for this type of control in terms of a minimum number of ACH.

Whereas use of UV disinfection and portable recirculating filtration units are mentioned as potential supplements, the specified minimum ACH is the design ventilation rate within the isolation room which must be met and thus becomes the focus of both design and compliance. In practice, the presence of unexpected stagnant air regions due to poor HVAC design and/or placement of furniture and equipment means that the dilution ventilation approach of delivering specified ventilation rates of "clean" air to the entire room for purposes of diluting unwanted contaminants provides no guarantee of good control of infectious airborne contagion [Memarzadeh and Jiang 2000].

Even under the rare circumstance of very good mixing, the dilution ventilation approach is limited in that to achieve the very high removal efficiencies appropriate for a serious infectious disease, a substantial number of ACHs are required. In addition, as the desired removal efficiency increases, additional small increments in efficiency require increasingly larger increases in the ventilation rate due to the logarithmic nature of contaminant decay. For example, if an infectious patient undergoes a coughing spell, which generates a given level of respirable contaminant floating throughout the room, one can calculate the time required (based on a given ventilation rate) for the concentration of respirable aerosol to reduce to some desired fraction of the original concentration (once the coughing spell has ceased). In equation form, this can be determined through a slight manipulation of the purging equation used in industrial ventilation to reduce contaminant concentrations below some desired exposure level [ACGIH 2004]:

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

where:

C_2 = Reduced concentration

C_1 = Original concentration (assumed uniformly dispersed)

Q = Ventilation rate

V = Room volume

Δt = Elapsed time

Dividing both sides by C_1, taking the natural logarithm, and solving for Δt yields

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

The *V/Q* term is the inverse of the room's ACH. For a given C2 and C1, the removal efficiency can be calculated by:

$$\text{Removal efficiency (\%)} = \left[1 - \left(C_2 \div C_1\right)\right] \times 100$$

Table 2 shows the required time in minutes for removal efficiencies of 90 percent, 99 percent, and 99.9 percent for the given ACHs. However, the times reported in the table assume a mixing factor (K) of 1.0 (perfect mixing throughout the room that maximizes the dilution effect). In reality, we know that most ventilation systems are unable to provide such perfect mixing, and we must multiply the required time identified in the table by the actual mixing factor. (Mixing factors for dilution ventilation can vary from one, for ideal mixing, to over ten for poor mixing. As a rule of thumb, a mixing factor of three can be assumed for a room with 12 ACH and good air movement [ACGIH 2004, Francis] Curry National Tuberculosis Center 2004].)

Table 2. Air changes per hour (ACH) and elapsed time required to achieve a desired removal efficiency*

ACH	Minutes Required for the Desired Removal Efficiency		
	90%	99%	99.9%
2	69	138	207
6	23	46	69
12	12	23	35
16	9	17	26
24	6	12	17
48	3	6	9

Using the values from Table 2, we can see that for a patient room with 12 ACH, which we assume is designed with good air movement (K = 3), it will take 36 (3 × 12) minutes to remove 90 percent of the infectious aerosol and over an hour to remove 99 percent, assuming that the patient generates no additional airborne infectious aerosols during this decay period.

Potential approaches to improve the performance of dilution ventilation include enclosing the source within a smaller containment zone volume, thus achieving a higher number of ACHs for the same exhaust flow rate, and incorporating strategically directed airflows that capture and remove a large percentage of the source contaminant before it has a chance to mix and dilute with room air. For a given flow rate, the smaller the containment zone, the higher the resulting ACH within this zone and thus the shorter the time required to achieve a desired removal efficiency (assuming equivalent mixing factors). The directed airflows reduce the contaminant's ability to spread into the outer perimeters of the room and thus reduce the required time for the overall room to achieve a desired removal efficiency.

The American Conference of Governmental Industrial Hygienists (ACGIH), a professional organization whose focus is on the recognition, evaluation, and control of occupational exposures, recommends four limiting factors before proceeding with a dilution ventilation for health approach. These factors include: (1) the quantity of contaminant generated must not be too great, or the airflow rate required for dilution will be excessive; (2) workers must be far enough away from the contaminant source or the source must be released in sufficiently low concentrations to maintain worker exposures below desired levels; (3) the toxicity of the contaminant must be low; and (4) the evolution of the contaminant must be uniform [ACGIH 2004]. One could easily argue that in the case of the infectious patient requiring airborne isolation, at least two of these factors (worker distance and contaminant toxicity) are probably not met.

The above discussion demonstrates why local exhaust ventilation (LEV) systems, i.e., systems designed to capture and remove source contaminants prior to their escape into the room environment, are the preferred ventilation technique for many contaminants, especially those whose toxicity (or infectiousness in this case) requires higher levels of control. There are three broad types of hoods used in LEV systems: *enclosing hoods,* which completely or partly enclose the contaminant generation point; *exterior hoods,* which are positioned adjacent to the contaminant source without physically enclosing it; and *receiving hoods,* which take advantage of contaminant momentum formed during the contaminant-generation process to receive and remove the contaminant from the working environment [ACGIH 2007a]. The performance of enclosing and exterior hoods depends upon the ability of the induced flow rate to capture and remove the source contaminant before it has a chance to mix with the overall room air. The ACGIH recommends ranges of design capture velocities for airborne contaminants on the basis of their physical properties and toxicity. For airborne droplet nuclei, which are released into relatively still room air at minimal velocity (their small size causes them to lose particle momentum very quickly), the recommended range is 50–100 feet per minute (fpm); the upper end of the range is indicated for higher-toxicity contaminants [ACGIH 2007b]. Once the design capture velocity is selected, the required flow rate and pressure requirements for the LEV hood can be determined with use of design equations specific to the hood geometry and distance from the source.

For patients in a hospital isolation room, their mouths and noses are the sources of airborne contaminant that must be controlled; however, the 100-fpm capture velocity prescribed above will likely cause discomfort for many patients. ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy,* provides guidance on acceptable environmental conditions, including wind velocity, which are anticipated to be acceptable to a majority of room occupants (85 percent or greater, or 80 percent or greater, depending upon edition) [ASHRAE 1992, 2004]. Up through 2010, which covers the period within which this research was conducted, Standard 55 provided a design equation for determining whether room currents will be perceived as acceptable or unacceptable (unwanted drafts):

$$PD = (93.2 - t_a) \times (\varpi - 10)^{0.62} \times (4.0 \times 10^{-5} \times \varpi \times Tu + 0.066)$$

Where: PD = Percent dissatisfied (generally acceptable if <15–20 percent)

t_a = mean air temp (°F)

ϖ = mean air speed (fpm)

Tu = Turbulent intensity (%) = $(SD_{\varpi} \div \varpi) \times 100$

and SD_{ϖ} = Standard deviation of air speed.

Note that for conventionally ventilated spaces with *Tu* around 50 percent and a design air temperature of 75 degree (°) F, this equation, solved to achieve a PD just below 15 percent, results in a design air speed of 30 fpm; solved to achieve a PD just below 20 percent (the current recommended threshold), it results in a design air speed of 37 fpm. In the 2010 edition of the same standard, ASHRAE eliminated the PD equation shown above and replaced it with a much more detailed set of criteria that allows for a greater diversity of environmental conditions. From the allowable air speed perspective, the most restrictive of these criteria, applicable when operative temperatures are below 72.5°F, prescribes an upper air speed limit of 30 fpm.

Clearly, for an adaptation of industrial ventilation techniques to be found acceptable to the patient population, it will need to function at a much lower capture velocity than that recommended for industrial environments. One method to increase the effective capture of contaminant at lower capture velocities is to increase the level of enclosure around the source. Increased enclosure helps to eliminate interfering cross-drafts at the source generation point, and the enclosure boundaries (if properly allocated) help to direct the capture velocity streamlines in a more uniform pattern towards the hood. Thus, one method to applying LEV control approaches to AII rooms could be through the use of an external exhaust hood, such as a ventilated headboard, with an increased level of enclosure containing the contaminant source, the patient's head. The enclosure design could attach directly to the top and two sides of the ventilated headboard and extend forward over the head of the bed, acting, in effect, as a hood forming a three-sided enclosure over the source. The bed would form the fourth side of the enclosure. In this manner, air that flowed into the LEV would first have to flow over/around the source, thus pulling any contaminant with it into the ventilated headboard, after which it could be passed through a HEPA filter and returned to the room.

A limiting factor to the success of any ventilation control approach to reduce potentially infectious airborne contaminants will be the level of mobility demonstrated by the patient. If the patient is sufficiently mobile to move beyond the controlled zone of aerosol capture, then the ventilation control will have lost its ability to directly capture the contaminant and any protective factor will result solely from the dilution ventilation in the general room environment.

Summary of Background Issues and Recent Events

The history of AII theory and control reveals a persistent tug of war between the research community and healthcare practitioners. Aerosol scientists and health researchers have historically advocated the concepts of airborne isolation and respiratory protection when laboratory and/or animal research indicates the ability of a disease to spread via the air. The medical community has historically been reluctant to accept the airborne contagion theory for any disease without overwhelming human epidemiological evidence supporting airborne transmission and an absence of any other plausible means of transmission. Rules governing human subjects research make such incontrovertible human epidemiology difficult to obtain, and when diseases spread naturally, it is very difficult to exclude every possible opportunity for shared or secondary contact with a source case. This difficulty could partially explain the paucity of diseases requiring airborne precautions. The reluctance to adequately consider airborne transmission was evident in the response by the WHO to the 2003 SARS epidemic, when WHO announced a lack of evidence that SARS was in fact airborne and also described incidents of apparent airborne spread to be due to "super-spreaders" [WHO 2003]. This was in contrast to public statements made months earlier by both Canadian Health Officials and the CDC that "…you need to probably be 100-percent adherent to the recommendations about airway precautions or airborne precautions, and that's because we know that there are certain patients that appear to be very highly infectious" [Gerberding 2003]. Perhaps, if affordable and effective airborne isolation capability were available, the medical community might be more prepared to err on the side of caution earlier in the process.

History might be prepared to repeat itself in regards to the desire to dampen consideration of the airborne transmission theory. As planning efforts have increased in preparation for a potential human-to-human outbreak of avian influenza, some public health planners seem to be distancing themselves from the airborne theory. The CDC's 2003 *Guidelines for Environmental Infection Control in Healthcare Facilities* clearly identifies influenza viruses in the table of microorganisms associated with airborne infection transmission [Sehulster et al. 2003]. However, infection control guidance available from the CDC topic page on influenza (www.cdc.gov/flu) does not acknowledge the airborne route [CDC 2007]. The *HHS Pandemic Flu Preparedness Plan* (available at www.pandemicflu.gov) appears to acknowledge the airborne route as a possible mode of inhalational transmission, at least over short distances. It then recommends the use of AII rooms, *if they are available,* and only during "special procedures" that may have an increased risk of aerosol generation. This guidance appears to imply a belief that the AII rooms will provide a meaningful and real-time protective effect against short-range transmission of cough-induced aerosol. Given the repetitive nature of the source, the immediate proximity of the attending healthcare workers, and the time delay required to achieve meaningful concentration reductions, this implied belief appears to contradict what is known about dilution ventilation theory. For day-to-day treatment, as of mid-2007 the pandemic flu guidance prescribed regular patient rooms, to include patient cohorting, combined with standard and droplet precautions [HHS 2007].

The healthcare burden during an infectious disease outbreak, such as the 2003 SARS experience or a large bioterrorism event, will fall disproportionately upon healthcare providers at the local level. Hospital emergency departments, outpatient clinics, even physician offices could be required to handle a surge of patients, many potentially infectious, others motivated by fear to seek medical care for their nonspecific "flu-like" or respiratory symptoms. In addition to providing patient care, healthcare facilities must also protect their patients, staff, and visitors from exposure to potentially infectious patients. During the period between April 15 and June 9, 2003, 74 SARS cases were reported to Toronto Public Health. Of these, 29/74 (39 percent) occurred among healthcare workers, 28/34 (38 percent) occurred as a result of exposure during hospitalization, and 17/74 (23 percent) occurred among hospital visitors [Health Canada 2003]. Under such scenarios, staffing shortages are probable, appropriate respiratory protection supplies will be in high demand, and the need to isolate potentially infectious patients will exceed the availability of AII rooms.

Although the U.S. government has been working to address shortcomings in the nation's emergency medical response plan for extraordinary incidents, viable solutions that are applicable across multiple demographics have been slow to develop, are costly to implement, and often offer only a small-to-moderate improvement in isolation capacity. For example, a 2006 medical response plan developed by the Nevada Hospital Association reported a functioning AII capacity of only 216 beds across the entire state, with a surge capacity of 91 additional beds [Nevada Hospital Association 2006]. In total, there were 307 "available" AII beds to serve roughly 2.5 million residents plus an average of over 4 million visitors over any given month [U.S. Census Bureau 2007; Nevada Commission on Tourism 2007]. Recent federal government reports indicate that the Nevada example was not unique and that the U.S. healthcare system as a whole generally lacks the patient isolation capacity to handle a significant airborne infectious epidemic or bioterrorism event [Dames 2004; Heinrich 2003; U.S. General Accounting Office 2003]. In addition, the American Hospital Association reports that the U.S. managed care system has dramatically reduced the availability of open inpatient hospital beds, to an average proportion of 4 to 6 percent of total bed capacity, a number destined to be overwhelmed in the event of a pandemic [Marghella 2005].

Government estimates indicate that the costs to prepare healthcare capabilities for a large biological emergency could reach $500 million for a major city [Dames 2004; Heinrich 2003; U.S. General Accounting Office 2003]. Attempts to identify alternative isolation approaches have been short on details and long on controversy, attracting substantial criticism from within the medical community [Yee 2003; Evans 2002]. Recommendations prepared by the CDC for community-level preparedness and response to SARS recognize that surge demand for AII rooms may easily overwhelm hospital capacity. When an insufficient number of AII rooms is available, CDC recommends placing patients in private rooms (non-AII rooms) and/or cohorting patients with other known SARS cases [HHS 2007; Kanof 2003; CDC 2004b]. The CDC guidance includes a few nonspecific references to the use of portable filtration units and other engineering controls to assist in addressing surge patient isolation requirements; however, more guidance is needed regarding

their selection and effective use [CDC 2004b]. Individual hospitals and researchers who have identified their own surge response strategies also tend to identify response plans that incorporate large-area cohorting, often within nontraditional treatment areas and sometimes augmented with negative-pressure filtration equipment, or the approach relies upon using portable ventilation units to convert traditional patient rooms into negative-pressure rooms, with little to no consideration of the strategy's impact upon pressure relationships within adjacent areas or the adverse demands placed upon the facility's HVAC systems [Rebmann 2005; Rosenbaum et al. 2004; University of Minnesota 2006]. One general commonality with the aforementioned surge isolation strategies is a minimally apparent consideration of direct methods (beyond respiratory protection) to reduce potential airborne infectious exposures to the healthcare providers who would have to enter these areas.

Problem Statement

Given the identified shortage in airborne isolation capacity within the U.S. healthcare system and the limited funding available to develop engineered isolation capacity on a national level, an affordable alternative to engineered isolation rooms is needed. This alternative must

(1) utilize a "universal design" capable of providing surge airborne isolation capacity for epidemic and bioterrorism events in a variety of healthcare environments; and
(2) reduce the potential exposures to healthcare providers and other facility occupants to airborne infectious aerosol.

Purpose and Scope

The purpose of this research was to evaluate portable filtration technology combined with increased levels of containment (as opposed to general room dilution) and directed airflows to provide expedient airborne isolation capability to a variety of healthcare settings not currently equipped for such isolation. The selection of this technology was fueled by its compatibility with existing ventilation systems, its affordability, and its recognition in published literature as an available engineering control to assist in patient isolation [Marier and Nelson 1993]. The research scope included (1) identifying uniform design parameters (configuration, flow rates, operational parameters, etc.) for at least two approaches to expedient airborne isolation applicable to real-world healthcare environments, the first using a zone-within-zone dilution filtration approach and the second using a local exhaust ventilation approach; (2) development of test protocols to challenge the containment and exposure reduction effectiveness of the evaluated configurations, using airborne infectious-sized surrogate contaminants; and (3) the documentation, evaluation, and interpretation of the performance that each expedient isolation approach can be expected to provide.

These primary questions were answered by the research:

1. Can "generic" expedient isolation enclosures be developed that are capable of rapid deployment (installed, qualitatively checked, and patient-ready in

under 3–4 hours) and isolation containment of airborne droplet nuclei within a designated patient area/room?
2. In addition to providing containment within the isolation zone, do the generic expedient isolation enclosures reduce exposures for attending healthcare workers or other room occupants?
3. For real-time concentration reductions due to source control provided by the expedient isolation configuration (as opposed to an engineered AII room's diluted removal), what is the *protective time equivalent (PTE)* (equivalent time delay to achieve the same level of reduction using 12 ACH dilution ventilation only) provided by the engineering control intervention?
4. What are the key design and performance factors (physical design parameters and configuration, entry gap widths, interpretation of qualitative testing, etc.) which should be incorporated into the design of an expedient airborne isolation area regardless of set-up location?
5. Does the portable filtration equipment and enclosure negatively affect environmental comfort parameters (temperature, cross-draft velocity)? If so, what installation precautions are necessary to mitigate identified adverse impacts?

Chapter II

Methods and Materials

The research was performed in multiple healthcare settings not currently engineered for AII. Selected locations were an even distribution of two urban hospitals and two smaller, rural hospitals, all located within the states of Oklahoma and Kansas. The exact rooms, corresponding dimensions, or design features were not known prior to testing and were determined by facility availability. The aim was to identify a diverse set of locations with varying physical and HVAC operational designs. Each facility received repetitive evaluations of two expedient isolation design variations, one of which was a two-patient configuration using a freestanding filtration unit and the other a single-patient configuration using a ducted filtration unit. Figure 5 shows the two types of portable filtration equipment used to establish the two expedient isolation configurations evaluated in this study. Results from early feasibility research had identified these two configurations as likely candidates for additional testing. A peer-reviewed journal article, published in the *Annals of Emergency Medicine*, discussed a portion of the preliminary research and findings [Mead and Johnson 2004]. A copy of this article is provided in Appendix A. In an effort to assist in the healthcare industry's acceptance of an expedient airborne isolation configuration as an alternative design under emergency circumstances, the current research sought consistency with three key design and operational criteria currently applied to engineered airborne isolation rooms:

- **Patient area**: Minimum of 100–120 square feet per patient bed [American Institute of Architects 2001].
- **Volumetric flow rate**: Flow rate (Q) sized to provide a minimum of 12 ACH within patient room (regardless of any smaller containment zone) [American Institute of Architects 2001].

- **Airflow velocities:** Within the vicinity of the patient's head, maximum airflow velocities (V) were limited to levels consistent with those published in ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy* [ASHRAE 1992, 2004]. Thus, physical hood parameters were adjusted accordingly to target velocities across the patient's head to approximately 30-35 fpm.

Figure 5. Photographs of some of the portable HEPA filtration equipment used during the expedient isolation research. A portable freestanding unit with nonducted inlet (*left*) and a portable dust-control unit, capable of ducted or freestanding operation (*right*).

Other design and operational parameters were to be experimentally identified from the investigative process. The two isolation approaches identified for investigation were the *zone-within-zone* approach, which utilized a smaller containment zone within the overall patient room, and the *ventilated headboard* approach, which used a local exhaust ventilation design with semi-enclosing hood to control patient-originated contaminants.

Expedient Isolation Configuration Descriptions

In ventilation system design, a "zone" is the space served by a ventilation system. The *zone-within-zone* isolation approach involved establishing a high-ventilation-rate inner isolation zone within a larger ventilated zone, by enclosing and ventilating the space immediately around an infectious patient's bed within a ventilated room. The approach relied upon a high dilution ventilation rate within the smaller contained inner isolation zone to rapidly dilute airborne contaminant levels within that space. This smaller inner zone was defined using a floor-to-ceiling retractable curtain with a designated curtain gap as the entrance point. The inner zone was located within a larger outer zone, which was defined by the overall patient room boundary. Air was exhausted from the inner zone through the use of a

freestanding HEPA filtration system that utilized a nonducted air inlet. The HEPA system was positioned to serve two patient inner-zones simultaneously, with no exchange of contaminated air between the inner zones. (A more thorough description and diagram [Figure 12] of this setup are discussed later, in this chapter's *Field Equipment and Methodology* section.) The goal was to not only contain the contaminant within the inner zone but also direct the airflow within it to capture the contaminant and pull it into the filtration unit. Such directed airflow limited the mixing of contaminated air into the worker-occupied areas of the inner zone. Combining this protective effect with the higher air exchange/ACH rate of the inner volume (in comparison with the total room) was intended to yield a more rapid dilution of airborne contaminant. The containment aspects were also anticipated to reduce contaminant migration throughout the patient room, thus reducing the opportunity for surface contact and fomite exposures.

For design purposes, three predetermined parameters of importance were as follows: (1) overall room floor areas of selected patient rooms would be consistent with the AIA recommended guidelines; (2) the inner isolation zone would be based upon the area demarcated by the existing privacy curtain; and (3) the volumetric flow rate provided by the HEPA filtration system would be greater than or equal to 12 ACH, based on the overall patient room volume. Experimentally defined design parameters were to include (1) the width and height of the curtain gap into the inner isolation zone, which, when multiplied by the gap height, determined the entrance open area into inner zone and (for a given ventilation flow rate) the resulting makeup air velocity through this opening, and (2) whether to seal or "blank-off" HVAC supply terminals located within the inner isolation zone.

All other routes of makeup air to the inner zone were minimized. The velocity of the makeup air through the curtain gap entrance largely impacts the flow streamlines between the entrance and exhaust points; thus, in order to direct these streamlines over the point of contaminant generation (i.e., the patient), the curtain gap setting was identified with a hand-held smoke generator and flow visualization techniques that were intended to optimize the flow streamline path across the patient source and into the HEPA inlet with a minimal amount of turbulent mixing.

An important operating parameter for the zone-within-zone isolation approach was its ability to interact with existing HVAC supply louvers or exhaust grilles. Exhaust grilles whose locations were within the confines or adjacent to the entrance of the inner containment zone were sealed with tape and plastic. For purposes of the experimental protocol, exhaust grilles were also blocked if they were located near the room's entry door. This was done to limit the inflow of ambient aerosol from outside the patient room that could potentially be counted by the aerosol monitors and adversely impact the reduction performance ratios. This was only done during the control-on conditions, as the influence of ambient aerosol would have a greater impact (on a percentage basis) during these test scenarios and the contribution of the exhaust systems to overall room airflow during control-off conditions was seen as too significant to ignore.

For each zone-within-zone field study, three HVAC conditions were targeted for evaluation, with the objective to identify the impact of HVAC supply louvers upon

the containment performance and environmental comfort conditions within the inner zone. These conditions were (1) a “no-control” condition without HEPA filtration or HVAC manipulation, (2) a “control-on” condition with the HEPA system activated and the HVAC supply louvers left open, and (3) another “control-on” condition with the HEPA system activated and the HVAC supply louvers sealed closed. After initial results were observed at the first field site, the second condition was altered to deflect the incoming HVAC supply air away from the patient and toward the HEPA filtration unit. This was done to accommodate the benefits of the tempered supply air while reducing the potential for HVAC supply air to disturb the directed streamlines carrying patient-generated contaminant into the HEPA filtration unit.

The *ventilated headboard* expedient isolation approach relied upon an LEV configuration to create localized capture of patient-generated contaminant before the contaminant had an opportunity to dilute throughout the overall patient room. A semi-enclosing hood (retractable when required for extensive hands-on patient care) extended over and along both sides of the pillow area of the patient bed and assisted in establishing parallel flow streamlines across the contaminant generation point (the patient’s head) and into the ventilated headboard, without requiring excessive capture velocities to overcome potential room cross-currents. The ventilated headboard was ducted to a small, portable HEPA filtration unit, similar to those used to contain dust and other aerosol contaminants during construction renovation activities in healthcare facilities. For design purposes, the minimum patient area, volumetric flow rate, and airflow velocity parameters for this approach were selected on the basis of the previously mentioned criteria (100–120 ft^2, $Q \geq$ 12 ACH, V ~ 30 fpm). With these parameters predetermined, the remaining design parameters related to the size of the ventilated headboard, the hood depth, and any manipulation of the room HVAC.

The ventilated headboard’s width was selected to be slightly larger than the width of the bed to enable the hood’s side curtains to drop straight down to the floor. The headboard’s leading edge was positioned slightly above mattress height, effectively allowing the mattress itself to act as the fourth side of the enclosure. The top height of the headboard was determined on the basis of that needed to continue enclosing the head position when the bed was in an inclined position. Headboard height was also selected to be compatible with existing wall-mounted equipment (lights, oxygen supply, electrical outlets, etc.). Overall, the face area of the ventilated headboard was selected so as not to exceed the maximum allowable airflow velocity near the patient’s head position at the volumetric flow rate used.

The headboard design parameter to be determined experimentally was the depth required for the hood to extend out, away from the ventilated headboard. Within the field of industrial ventilation, the recommended minimum hood depth was 75 percent of the largest vertical dimension (width or height) of the LEV without the hood in place [ACGIH 2004]. The hospital room is not an industrial environment, so one might expect less interference from cross-currents: however, given the reduced capture velocities that resulted from requirements to accommodate patient comfort conditions, the selected hood depth played a critical role in ensuring consistent source capture without interference from room cross-

currents. At the same time, a hood that extended too far may leave the patient with the feeling of being placed within a tunnel and may also limit patient access or interaction with healthcare providers. Thus, qualitative smoke tests were used to identify a minimum effective hood depth (D_o) and a slightly larger hood depth (D_o + 8 in) as the two "control-on" conditions for quantitative evaluation. Based on the preliminary field testing, the 8-in additional hood depth was anticipated to approximate the previously discussed "75 percent of largest dimension" rule of thumb.

For purposes of the ventilated headboard configuration, exhaust grilles whose locations were adjacent to the patient bed were sealed with tape and plastic. Supply registers whose induced airflows were shown through qualitative smoke tests to interfere with the unidirectional in-flow of air into the ventilated headboard's hood were deflected. As with the zone-within-zone configuration, exhaust grilles were also blocked if they were located near the room's entry door. In a real-world scenario, as long as the HVAC operation did not interfere with the ventilated headboard operation, decisions regarding the need to seal off supply or exhaust louvers could be made on the basis of facility-specific policies or capabilities.

Combining the two hood depth conditions and the control-off condition intended for comparison, evaluation of the ventilated headboard expedient isolation approach resulted in three test conditions: (1) a control-off condition with HEPA off and no hood in position; (2) a control-on condition with HEPA activated and the hood enclosure extended to provide a hood depth of D_o; and (3) a second control-on condition with HEPA activated and the hood extended to provide a hood depth of D_o + 8 in.

For both the zone-within-zone and ventilated headboard test configurations, the doors to adjacent restrooms remained closed throughout the test runs. A life-sized mannequin was placed into the patient bed within the isolation zone and covered with a hospital blanket to simulate the source patient. The patient mannequin remained in a flat bed posture for all of the test scenarios. The source release points, shown in Figure 6, were adjacent to the mannequin's mouth.

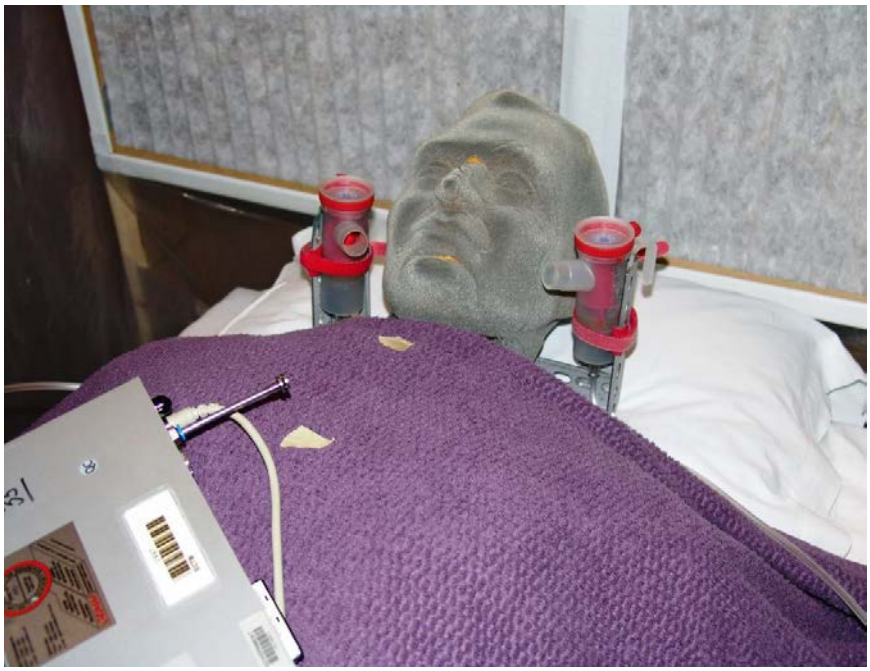


Figure 6. Photo of patient mannequin positioned in front of a ventilated headboard shows source generators (nebulizers) positioned next to the mannequin's mouth and an aerosol sampler positioned in the center of the mannequin's chest.

Surrogate Aerosol Source Generation—Protocol Development

The research effort supported by the droplet nuclei generation protocol was designed to evaluate the effectiveness of engineering control interventions to contain surrogate infectious aerosol and to reduce potential exposures to healthcare providers and other room occupants. Performance was determined by measuring the airborne concentration of droplet nuclei of known size at key locations within a hospital treatment room. The success of an intervention was evaluated by the intervention's ability to reduce airborne concentrations at the various measurement points, relative to those observed during the "control-off" conditions. A randomized complete block experimental design was selected for the intervention evaluation. However, in order to get a meaningful comparison between the "control-on" and "control-off" test conditions within a particular block, repeatable aerosol generation rates were required. Thus, the objective of this substudy was to identify a generation protocol capable of producing consistent concentrations of airborne droplet nuclei within the targeted size range.

Testing Platform and Set-up Description

An Open-Jet Wind Tunnel (Airflow™, Part No: 9020066[29-06-1999], Buckinghamshire, England; modified as described) was the basis of the controlled testing platform used for development of the aerosol generation protocol (Figure 7). The wind tunnel's variable air supply system was replaced with a portable filtration unit equipped with a variable-speed fan and HEPA filtration (Abatement Technologies Inc., Model PAS1000, Suwanee, Georgia). This fan unit provided the ability to positively pressurize the system with a variable supply of highly filtered

air. A 4-in-wide slip collar connected the fan's 10-in diameter discharge to a 10-in by 8-in reducing collar. Attached to the reducing collar was an 8-ft-long testing segment. To avoid permanent modification to the wind tunnel apparatus, the leading 4-ft segment of the wind tunnel's 8-in diameter duct was replaced with this temporary 8-ft testing segment of 8-in-diameter galvanized spiral duct.

A Pari LC Star nebulizer with ProNeb Ultra compressor (Model 85B 0000, PARI Innovative Manufacturing Inc., Midlothian, VA) was selected for evaluation. Within the testing segment, locations were chosen for introducing the nebulizer output into the moving air stream, for measuring airflow parameters within the duct, and for measuring aerosol concentrations within the moving air stream. Beginning 10 in downstream of the start of the testing segment, a ¾-in by 8-in copper pipe was permanently inserted into the side of the spiral duct and oriented downstream at an approximate 45-degree angle to the duct axis. The copper pipe allowed introduction of the nebulizer output into the center of the HEPA-filtered air stream. The proximity of this introduction point to the fan and reduction collar facilitated mixing of nebulizer output within the moving air stream. Moderate sanding of the copper pipe's inside diameter resulted in a tight-fitting connection between the nebulizer output nozzle and the copper pipe's inside diameter. Seven feet downstream of the start of the testing segment, two 1/8-in diameter holes, offset by 90 degrees, were drilled into the top and side of the duct to allow a 1/8-in by 12-in pitot tube (Dwyer, Michigan City, IN) access for perpendicular velocity-pressure traverse measurements. The pitot tube was connected via tubing to a handheld micromanometer (TSI, Inc., Airflow Meter 8386A, Shoreview, MN) for actual pressure measurements. This pitot traverse measurement location was sufficiently downstream of duct-segment fittings to be consistent with the 7 to 10 duct diameters recommended by the ACGIH Industrial Ventilation Committee [ACGIH 2007b] and well beyond the 3-duct-diameter minimum recommended by Guffey and Booth [1999] for two perpendicular pitot traverses. Six inches downstream from the pitot tube sampling location, a 3/16-in hole was drilled into the bottom of the duct to allow positioning of the omni-directional inlet of an aerosol spectrometer (Grimm Dust Monitors, Models 1.10x, Labortechnik GmbH and CoKG, Ainring, Germany) within the midstream of the duct airflow. The testing segment concluded roughly 6 in beyond the spectrometer sampling hole and was attached to the remainder of the wind tunnel with a slip-collar duct fitting.

The remainder of the airflow wind tunnel included 4 ft of straight 8-in duct, followed by a quick-release clamping arrangement for changing of the orifice plates used to measure airflow rates. This was followed by an additional 4 ft of straight 8-in duct and an expansion "smoothing chamber" equipped with perforated screens and a honeycomb flow-straightener that provided a uniform flow into the wind tunnel's contraction section and exit nozzle.

Modified Wind-tunnel for Lab Generation Tests

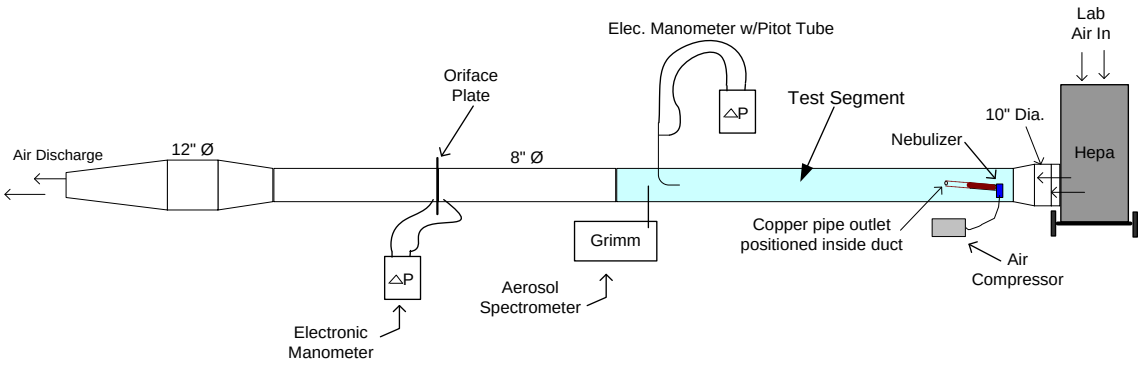


Figure 7. Schematic (7a) and photograph (7b) showing the testing platform used for development of the aerosol generation protocol.

Aerosol Generation Technique

Uniformly sized polystyrene latex (PSL) microspheres (Catalog No. 4016A, Duke Scientific, Palo Alto, CA) were aerosolized from water suspension as encapsulated aerosol whose water component quickly evaporated to leave the droplet nuclei (the PSL microspheres) afloat. The manufacturer's literature described the microspheres as uniformly spherical, with a nominal diameter of 1.6 μm (1.587 μm ± 0.025 μm) and a density of 1.05 grams per cubic centimeter (g/cm^3). The microspheres were insoluble and were supplied in a suspension of 1 percent solids. The liquid

component of the suspension was primarily deionized water, with trace amounts of surfactant and preservative. Since the PSL sphere density (ρ_p) was very close to unit density (ρ_o = 1.0 g/cm^3) and the particle diameter (d_p) was greater than 1 μm (i.e. minimal slip correction), the aerodynamic equivalent diameter (d_a) of these spheres could be calculated as follows:

$$d_a = d_p \left(\frac{\rho_p}{\rho_0} \right)^{1/2}$$

$$d_a = 1.6\mu m \left(\frac{1.05}{1.0} \right)^{1/2} = 1.64\mu m$$

which resulted in an aerodynamic particle size of 1.64 μm [Baron and Willeke 2001]. Thus, this particle size was consistent with the 1-to-3-μm size particles typical of tuberculosis bacteria, spores (including anthrax spores), and other infectious bioaerosols that remain airborne for long periods, are readily inhaled, and penetrate deep into the lung [Riley 1974].

The air-jet nebulizer operated at a pressure of 20 psi (138 kPa). At this operating pressure, a BIOS DryCal Primary Flow Meter (BIOS Model DCL-M, BIOS International Corp., Butler, NJ) was used to measure an air delivery rate of 1.7 liters per minute (Lpm) with the nebulizer attached.

A series of experiments were conducted to evaluate particle generation rates associated with combinations of one to three PSL microsphere suspension droplets per 8 ml or 10 ml of ultrapure water. Selection of these ratios as a starting point was based upon the success of the ratio demonstrated during the concept development phase of the dissertation research (3 drops per 10 ml).

During each trial, the nebulizer output was inserted into a ¾-in by 8-in copper pipe, which was mounted into the testing segment of the duct. By design, the nebulizer output was a mist of aerosol predominantly within the 1–5-μm size range, because these particles are ideal for pulmonary drug delivery [Leung et al. 2004; Geller 2006]. The nebulizer output traversed the copper pipe and entered the moving airstream within the testing segment, where the water component of the aerosol rapidly evaporated, resulting in the production of droplet nuclei that consisted of PSL spheres and/or whatever other residue may have originated in the nebulizer fluid or its compressed air source. Rapid mixing and dilution with the HEPA-filtered air stream helped to minimize agglomeration of the droplet nuclei [Friedman and Horstman 1974]. After flowing downstream, the airborne particles in the moving air stream were sized and counted with a Grimm real-time light-scattering aerosol spectrometer (Model 1.108 or 1.106, Grimm Dust Monitors, Labortechnik GmbH and CoKG, Ainring, Germany). These instruments were designed for real-time particle counting with particle size discrimination into 8 or 15 (depending upon model) size ranges from 0.3 μm to 20 μm. The Grimm was programmed to operate in normal mode, which integrated and recorded particle counts within each size range over 1-minute intervals. These data were sequentially stored onto an internal

data storage card and subsequently downloaded onto a laptop computer for further analysis. Start and stop times for important events were manually recorded for later comparison with the data.

The downloaded data were imported into Microsoft Excel® for further evaluation. Since the PSL particles were 1.6 μm in diameter (d_a = 1.64 μm) and the ultrapure water in which they were suspended was minimally contaminated and therefore not expected to significantly affect condensation nucleus size, the variable of primary interest was the particle count between 1 μm and 2 μm.

Preliminary Work to Develop the Generation Protocol

Medical nebulizers of the type used in this research were generally designed for a drug delivery period of between 15 and 30 minutes [Le Brun et al. 2000]. For the Pari LC Star, a qualitative test was conducted to identify a duration between 15 and 30 minutes to use as the nebulization period in the droplet nuclei generation protocol. Nebulizer suspensions of 2 drops/10 ml and 1 drop/10 ml (PSL microsphere suspension/ultrapure water) were created and allowed to nebulize into the test apparatus until the suspension remaining in the reservoir volume was less than that required for aerosol nebulization. Graphic results (Figure 8) from these runs revealed that for both dilution ratios, a general slope transition appeared to occur roughly between 20 and 30 minutes of elapsed nebulization time. This was evaluated through an analysis of linear trend lines for the first 20 minutes vs. minutes 31–65 for each of the dosing concentrations. For a given dosing concentration, the intersection of the two trend lines approximates a slope transition point. Previously, the concept-development phase of this research had demonstrated that a 20-minute nebulization period was sufficient to allow aerosol migration throughout a multi-patient hospital room. Since the 20-minute period was consistent with the nebulizer's design intent and preceded the generation rate transition points identified on the graph, a 20-minute dosing period was selected for this protocol.

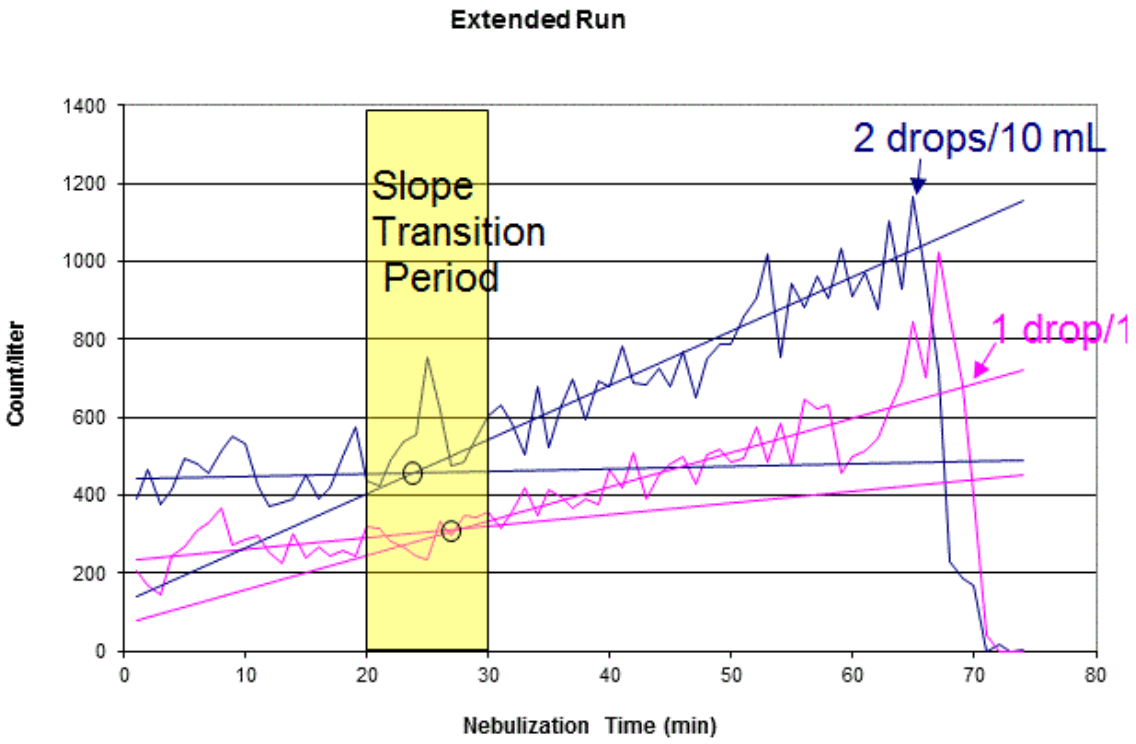


Figure 8. Variation with nebulization time of aerosol particle counts, per liter of air sampled, for the 1–2-µm size range. Extended nebulizer runs using two PSL microsphere suspension concentrations revealed an apparent aerosol generation rate inflexion point between 20 and 30 minutes of elapsed nebulization time.

Because the performance of the expedient isolation trials were to be evaluated in terms of “control-on” vs. “control-off” particle count ratios, the number of aerosol particles generated during the compared trials required consistency. Graphic results (Figure 9) from initial aerosol generation test runs revealed particle count concentrations with lower magnitude, followed by a large increase over approximately the first 10 minutes of nebulizer operation, before transitioning into a more consistent, slowly increasing concentration over time. Once the concentration jump occurs, the slowly increasing count/liter was consistent with prior research findings that revealed the concentration of solute within the nebulizer solution increased as nebulizer run time progressed, resulting in higher output concentrations [Rau 2002; Mercer et al. 1968].

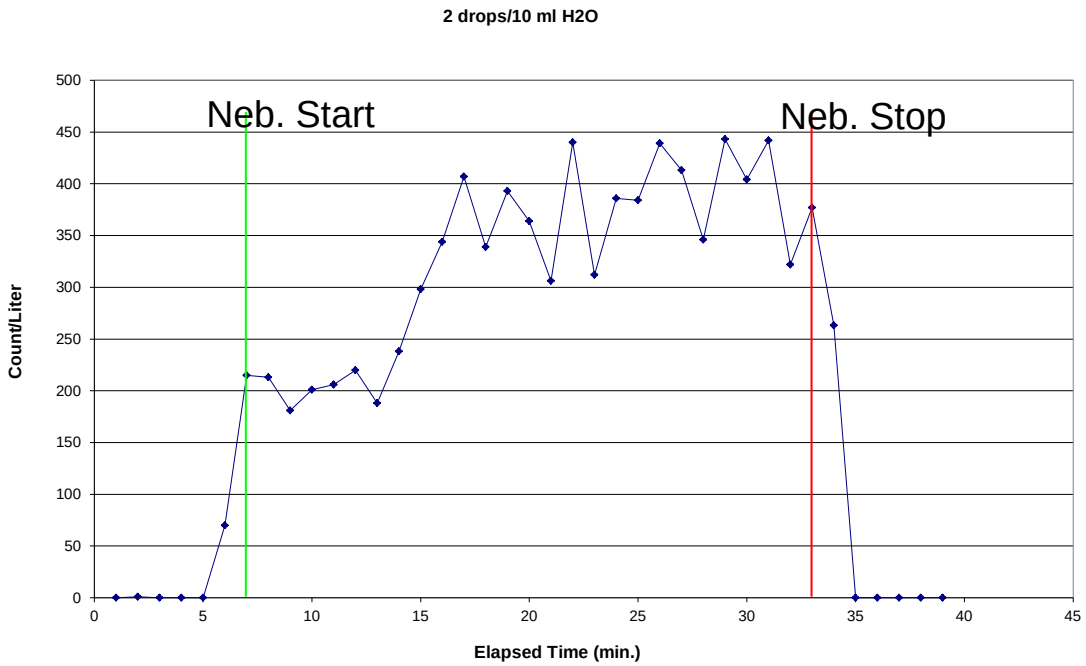


Figure 9. Graph of early nebulizer output, showing initial instability followed by an apparently steady concentration increase.

The exact cause of the initial reduced response and increased variability was uncertain; however, over a period of weeks, several steps were initiated through a series of sequential experiments in an effort to minimize the initial spike in concentration, to reduce variability, and to increase repeatability between test runs. The most important of these were (1) a 60 percent increase in the orifice plate diameter, which reduced static pressure within the testing platform and relieved the back pressure that was believed to be working against the nebulizer and retarding flow through the copper pipe, and (2) the use of dosing blends that combined ultrapure water and microspheres into a single batch of large enough volume to supply a block of up to four test runs. Figure 10 graphically demonstrates the changed output characteristics after implementation of these changes.

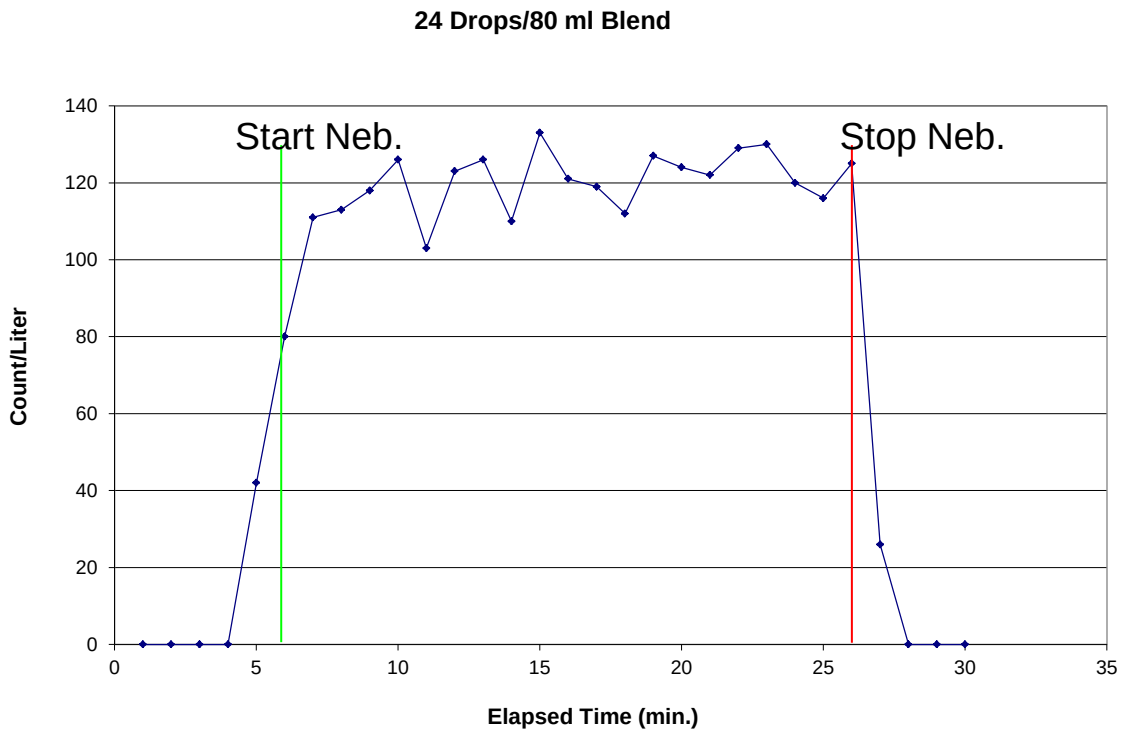


Figure 10. Droplet nuclei generation rates after reducing testing platform back-pressure and revising the PSL suspension formulation.

Although there was still a brief delay before the graph in Figure 10 reached "full response," the initial delay of 2–3 minutes was much shorter than the 10+ minutes observed in the earlier trials and reflected in Figure 9. In addition, the variability was greatly reduced (Figure 10: CV = 10.0 percent; Figure 9: CV = 29.4 percent). Also worth noting was that the improved variability was not due solely to the dramatic reduction in the delayed response between dosing start and elevated count observations. A comparison of the coefficients of variation calculated for minutes 11–20 ($CV_{11–20}$) of the two dosing scenarios revealed the following values: $CV_{11–20}$ = 4.7 percent (Figure 10) and $CV_{11–20}$ = 10.0 percent (Figure 9).

Another issue that affected the droplet nuclei generation protocol was one of apparent instrument "noise" or lack of precision in the reporting of particle counts for aerosol below 2.0 μm. Although the manufacturer's literature claimed a precision of only 1 particle per liter of sampled air, actual aerosol counts between 1 and 2 μm were logged solely as factors of five, appearing to indicate some sort of truncation error. Discussions with the manufacturer's representative revealed it was unaware of the issue, and it did not have an immediate solution. To reduce the potential adverse impact of noise for near-zero counts, the higher end of the evaluated dose options (3 drops microsphere solution per 10 mL of ultrapure water) was selected out of preference for its corresponding higher magnitude of droplet nuclei generation. In addition, for purposes of validating the droplet nuclei generation protocol, the Grimm spectrometer was switched from model 1.108 to an older model (1.106), which did not exhibit the lack of precision issue.

To reduce confounding of a consistent droplet nuclei generation rate by the generation of doublets or other agglomerates, it was important to nebulize a predominant percentage of aerosol droplets that contained no more than a single PSL sphere. Aerosol droplets that contained a single 1.6-μm sphere (i.e., singlets), after desiccation, appeared in the 1- to 2-μm-size bin of the aerosol spectrometer's data output file. In the 1960s, Otto Raabe developed formulae to identify the dilution of a concentrated suspension of monodispersed particles that was necessary to result in a desired singlet generation rate of monodispersed aerosol [Raabe 1968]. However, the use of these formulae required knowledge of the aerosol produced by the specific nebulizer, including the count median diameter (CMD) or mass median diameter (MMD) and the distribution of aerosol sizes (assumed to be geometric) that surround that estimate. When the dilution ratio was above 90 percent and the geometric standard deviation of the aerosol produced, σ_g was < 2.1, the relationship between the dilution ratio and the singlet generation rate could be represented as follows:

$$y \cong \frac{F(MMD)^3 \times e^{4.5 ln^2 \sigma_g}}{(1-R)D^3}\left[1 - \frac{e^{ln^2 \sigma_g}}{2}\right] \qquad \textit{Raabe Equation}$$

Where:

y = dilution ratio (new volume/old volume) after suspension was diluted with pure liquid

R = singlet ratio

F = fraction by volume of particles in the original stock solution

D = diameter of the monodispersed spheres

The rapid dehydration of aerosol leaving the nebulizer made the accurate measurement of aerosol size distribution a challenging task. Fast, minimally invasive techniques that do not alter the flow or back pressure of the nebulizer were required. The Pari LC Star nebulizer has been evaluated for its output characteristics, as measured through the use of laser diffraction [Standaert et al. 2001; Kwong et al. 2000; Ho et al. 2001]. Although the output from the Pari LC Star was a function of both its design and the solute being nebulized, the previous researchers have shown the Pari LC Star to be consistent with an MMD under 5 μm and a σ_g <2.1 [Standaert et al. 2001; Kwong et al. 2000; Ho et al. 2001]. For the purpose of using the Raabe equation shown above, an estimated MMD of 5 μm was selected, representing a worst-case (for doublet generation) selection within the Pari LC Star's range of expected aerosol size generation. The Raabe equation was mathematically rearranged and solved for *R* to reveal an estimated singlet ratio:

$$R \cong 1 - \frac{F(MMD)^3 \cdot e^{4.5ln^2\sigma_g}}{y \cdot D^3} \cdot (1 - \frac{e^{ln^2\sigma_g}}{2})$$

For an old volume = 1/12 ml per drop × 3 drops = 0.25 ml, new volume = 10 ml + old volume = 10.25 ml, y = 10.25 ml / (0.25 ml) = 41.0, MMD = 5 μm, σ_g = 2.0, D = 1.6 μm, and F = 0.01, the estimated R was approximately 99 percent. Thus, confounding or variability due to production of non-singlet PSL microspheres was not predicted to be a problem under the generation protocol used.

Validation of the Generation Protocol

On the basis of the previously discussed discovery process, a generation protocol was identified and submitted to evaluation for its ability to provide consistent concentrations of airborne particles between 1 and 2 μm. The steps of the generation and evaluation process using the previously identified equipment, supplies, and testing platform are identified below.

Preliminary Steps

1. The HEPA filter was activated for 10+ minutes to "clean out" the system (not applicable for repeat trials).
2. The electronic manometer was zeroed and then activated to log the pressure differential across the 163.82-mm orifice plate, with use of 2-sec averaging on 1-min intervals.
3. The HEPA's fan regulator was set at ~ 4:00 position; this resulted in a corresponding Delta P ~ .29" water gauge (w.g.) across the selected orifice plate.
4. The Grimms were activated for equipment warm-up.
5. The nebulizer was activated for 10+ minutes with only deionized, Type I, ultrapure water in the nebulizer cup. This was intended to "condition" the system and to monitor background (BG) counts.
6. Horizontal and vertical log-linear 8-pt velocity pressure (VP) measurements were conducted at the designated sample position, slightly upstream of the Grimm sample position within the duct, with use of a zeroed electronic manometer and pitot tube. These values were converted to velocities with the equation $V = 4005\sqrt{VP}$. Calculated velocities were averaged and multiplied by the duct area ($A_{8" \text{ duct}}$ = 0.35 sq ft) to determine the airflow rate (Q) in cubic feet per minute (cfm).

Test Run Scenario

7. To initiate a test run, the HEPA was left running from the preliminary setup and the Grimm was placed on standby mode.
8. A nebulizer cup was filled with 10 ml of ultrapure water and connected to the compressor's air supply tubing. The nebulizer cup (the "conditioning cup") was placed into position on the copper dosing tube and the air compressor was activated.
9. The Grimm memory was cleared, and logging was begun for BG counts (1 sample/minute) with the conditioning cup in place.

10. A dosing blend was created: 24 drops of 1.6-μm polystyrene microsphere suspension with 80 ml of the Type I, ultrapure water.
11. The dosing blend was swirled to mix thoroughly, and then 10 ml of the dosing blend was carefully transferred into a clean, graduated cylinder that had been pre-rinsed with the ultrapure water.
12. The graduated cylinder contents were poured into a clean nebulizer cup that was pre-rinsed with the ultrapure water. The nebulizer baffle/cap was replaced to create the "dosing cup."
13. Horizontal and vertical 8-pt log-linear VP measurements were conducted with a zeroed manometer and pitot tube to determine pretest duct flow rate.
14. After 3–5 minutes of Grimm measurements showing BG counts of zero in the size range of interest (1–2 μm), the conditioning cup was replaced with the dosing cup and the dosing start time was noted.
15. The nebulizer dosing cup was run for approximately 25 minutes and then switched back to the conditioning cup, and the dosing stop time was noted.
16. Additional VP measurements were collected as in Step 13 to calculate a post-test duct flow rate.
17. The Grimm was run for 5 additional minutes or until consistent zeroes appeared in the 1–2-μm range.
18. The Grimm was stopped/restarted to keep it conditioned and running.
19. The data file was saved and exported to a notebook computer.
20. The HEPA unit and nebulizer with conditioning cup were left on during preparations for the next run.
21. Steps 7–20 were repeated as desired.

Validation Results

Figure 11 shows a bar chart of aerosol counts according to size distribution for a data run conducted with the final droplet nuclei generation protocol.

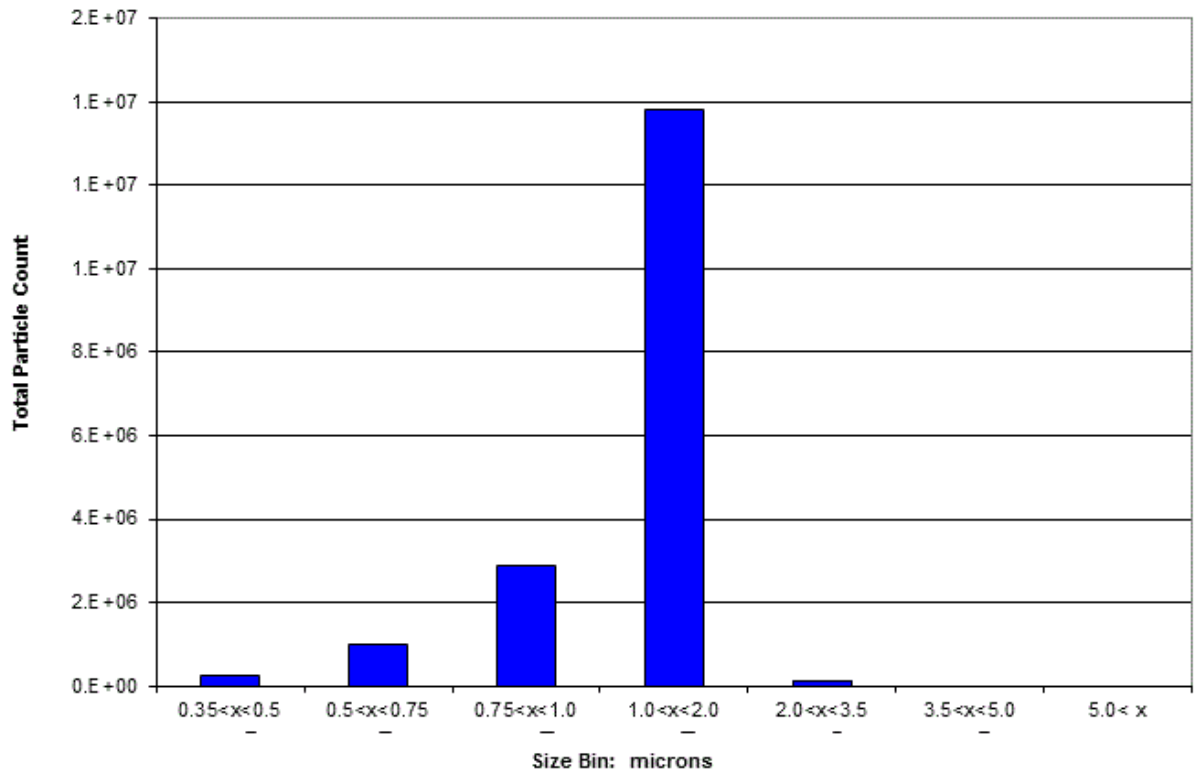


Figure 11. Total count distribution by size bin (microns) over a 25-minute nebulization period with use of 1.6-μm PSL microspheres and the described protocol.

Note that the aerosol particle sizes greater than 1 μm and less than or equal to 2 μm in Figure 11 were the predominant aerosol size fractions generated, constituting over 75 percent of all counts. Overall, aerosol particles 2 μm and smaller constituted greater than 99 percent of the observed particles, with fewer than 1 percent of observations between 2 and 3.5 μm and zero greater than 3.5 μm. The latter two points demonstrate the accuracy of Raabe's predictive equation and confirm that the creation of agglomerates of two or more PSL beads was less than 1 percent. Observed particles below the 1-μm size were probably due to residuals originating from the liquid PSL suspension (surfactant, water, preservative) or from nonfiltered room air used by the compressor to drive the nebulizer's output. Counts less than 1.0 μm were not included in this protocol evaluation or in future field studies that adopted the protocol.

During the protocol development and validation activity, a quick test was required to evaluate the consistency of the aerosol generation counts. To accomplish this, a control band approach was developed to monitor the particle counts between 1 and 2 μm associated with individual runs, within a 4-run block. Each block corresponded to an individual batch of diluted microsphere suspension. To determine the total particle count for an individual test run, the volumetric flow determinations collected in steps 13 and 16 of the protocol were averaged. This flow rate was multiplied by the elapsed run time (20 minutes) to get a total volume of flow for the 20-minute run. This volume was then multiplied by the average particle count

concentration observed between 1 and 2 μm over the first complete 20 minutes of Grimm sample time that followed the start of nebulization, resulting in the overall number of particles counted. The total count was determined for each of the four runs in an individual block, and a mean total count for the block was also calculated. Control boundaries were selected such that the total count for each of the individual runs within a block should not deviate from the mean total count for the block by more than 5 percent. In this manner, performance feedback was quickly collected and subsequent blocks could be initiated without protocol modification. Once the generation method was identified, this validation activity was repeated for a total of 8 blocks, though one of the blocks had to be disregarded because of an experimental error. Of the remaining 28 test runs (7 blocks × 4 runs/block), only one test run of one block reached, but did not exceed, the control limit.

The same seven blocks of test runs were then evaluated for the protocol's ability to repetitively produce consistent particle counts within each block (Table 3). Since only within-block consistency was required to establish meaningful performance ratios in the experimental design, all the data were normalized by dividing each test run's total count by the mean total count for the respective block. In this manner, the data were transformed into 28 data points normally distributed around an expected value of 1.0. Analysis of these 28 sample points revealed a mean of 1.0 (as expected) and minimal variance, resulting in 95 percent confidence limits that fell within $\pm$1 percent of the mean.

Table 3. Validation of the aerosol generation protocol's ability to repetitively produce consistent particle counts within each block.

Block/Run	20-min ave	Q ave (l/min)	20-min count	Block Mean	Normalized Count	Collective Statistics
8a	46.6	11188	10427216	10354700	1.01	
8b	46.6	11237	10472884		1.01	
8c	45.8	11286	10337976		1.00	**Mean (28 normalized counts) =** 1.00
8d	45.3	11237	10180722		0.98	
7a	49.2	11163	10984392	11082260	0.99	**Standard Deviation (SD) =** 0.0259
7b	49.95	11138	11126862		1.00	
7c	49.05	11212	10998972		0.99	**Standard Error (SE) =** 0.0049
7d	50.25	11163	11218815		1.01	
6a	59.75	11212	13398340	12701190	1.05	$\mathbf{t_{.025}}$ **=** 2.0520
6b	57	11163	12725820		1.00	
6c	53.5	11237	12023590		0.95	**Precision Error =** 0.0100
6d	55.95	11311	12657009		1.00	
5a	124.5	11238	27982620	28798809	0.97	**95% LCL =** 0.99
5b	131.2	11263	29554112		1.03	**95% UCL =** 1.01
5c	124	11287	27991760		0.97	
5d	131.7	11263	29666742		1.03	
4a	94.7	11164	21144616	21807347	0.97	
4b	95.35	11287	21524309		0.99	
4c	99.35	11213	22280231		1.02	
4d	99.35	11213	22280231		1.02	
3a	112.7	11189	25220006	26132064	0.97	
3b	113.75	11164	25398100		0.97	
3c	119.9	11287	27066226		1.04	
3d	119.7	11213	26843922		1.03	
1a	113.25	11164	25286460	25754761	0.98	
1b	113.85	11164	25420428		0.99	
1c	113.25	11263	25510695		0.99	
1d	119.5	11214	26801460		1.04	

NOTE: Block 2 was discarded due to error in PSL suspension preparation

Validation Conclusion

Given the high degree of precision in the results shown in Table 3, the benefit to be derived by additional test runs was determined to be minimal. For example, if one assumed that the standard error term remained consistent and 41 test runs were conducted, as opposed to the actual 28, then the resulting 40 degrees of freedom would yield a $t_{.025}$ statistic of 2.021 [Walpole and Myers 1993]. When multiplied by the standard error term, the resulting 95 percent confidence limits would have narrowed only from 0.990–1.010 to 0.991–1.010. Thus, the existing number of repetitions was considered to be sufficient and the aerosol generation protocol was deemed validated for the intended research purposes.

Field Equipment and Methodology

Upon hospital room selection, the room geometry, ventilation design, and ventilation parameters (volumetric flow rate, pertinent flow velocities) associated with the containment design were documented and a room schematic was drawn for each room environment, before any experiments were conducted. Two general expedient isolation configurations were evaluated: (1) the zone-within-zone total enclosure configuration used for multi-patient rooms and (2) the ventilated headboard with semi-enclosing hood configuration for single-patient rooms.

Configuration Setup

Zone-Within-Zone: This was configured to serve two patients simultaneously (Figure 12). Although inner zones were established for both patient positions, only one of these was challenged with surrogate contaminant aerosol. A life-size mannequin was placed in the bed at this position and covered with a hospital blanket to simulate the source patient. The inner zones required a physical containment perimeter encircling each patient bed and its surrounding work area, with a designated opening for makeup air and worker entry. Inner isolation zone boundaries were based upon the existing patient areas, defined by their cloth privacy curtains, as well as compatibility with HEPA filter placement within the overall room geometry. For some locations, this resulted in inner zone boundaries where the makeup air entrance and exhaust points were located at diagonally opposite corners of the inner zone. At other locations, the airflow entered near one corner and flowed directly across the pillow end of the bed to an exhaust point at the adjacent corner.

To construct the inner zone boundary, the existing cloth curtain was replaced with a floor-to-ceiling plastic curtain that followed the same curtain track. The plastic curtains were constructed with medium-weight (3.5- to 4-mil) plastic sheeting, sold in hardware stores as painting drop cloth. The top of the plastic curtain was double-folded, taped into place, and hole-punched to allow it to hang on the existing curtain hooks and track and thus be opened and closed. The curtain extended down to the floor, leaving an approximate ½-inch gap at the top due to the curtain hooks. This gap was sealed with tape and plastic or covered by a loose-fitting 12-in-long piece of plastic sheeting secured to the outer side of the curtain track, thus inhibiting airflow through the gap without interfering with curtain operation. This

resulted in greater dependence on the curtain entrance gap itself as the source of makeup air into the inner isolation zone.

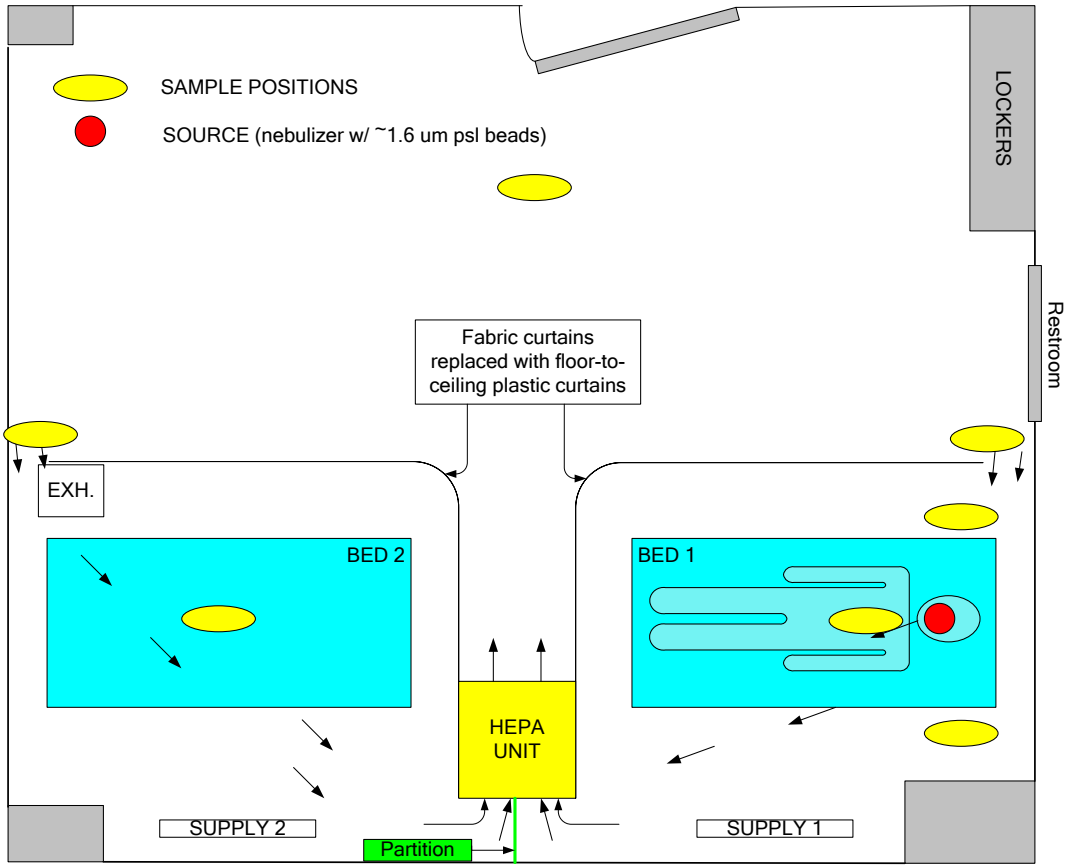


Figure 12. Example schematic of configuration setup and equipment locations for zone-within-zone expedient isolation.

The nonoperable portion of the curtain was sealed into place with tape and plastic, closing all gaps and thus making this portion of the curtain nonretractable. For the retractable portion of the curtain, a pocket fold was incorporated into the bottom of the curtain and a lightweight utility chain was inserted along the length of this fold to act as ballast. This feature allowed the curtain to be retracted for compatibility with real-world scenarios involving patient/equipment movement. During occupancy, the ballast held the bottom of the curtain snug to the floor and prevented it from being pulled inward when the inner zone was under negative pressure.

A freestanding portable HEPA filter with nonducted inlet was positioned equidistant between the two patient beds. The suction side of the HEPA filter served the inner containment zone, placing it under negative pressure relative to room pressure, filtering the captured air and returning the clean air to the outer zone surrounding the inner containment zone. The patient bed heights were adjusted so that the mattress height was consistent with the HEPA inlet height. A plastic sheeting vertical partition was built between the center of the HEPA inlet and the adjacent wall in order to separate the two inner isolation zones. In addition, a plastic-

sheeting baffle was positioned like a “dust ruffle” to restrict the airflow path from beneath the bed toward the HEPA unit. For each isolation zone, the nonoperable section of curtain from each inner isolation zone was taped to the sides of the HEPA filtration unit, and any remaining gaps were sealed with tape and plastic sheeting.

The HEPA system’s variable speed control was adjusted to achieve a targeted 12 ACH based upon the overall room volume. Regardless of the capture/containment results within the inner zone, this criterion provided a minimum aerosol dilution/removal performance for the entire patient room equivalent to that required for a newly constructed AII room. The filtration equipment was placed to avoid intrusion upon patient care activities. To enable remote activation without room entry, the power to the HEPA unit was supplied by an extension cord that led out to the corridor.

During control-on test conditions, HVAC exhaust grilles were sealed with tape and plastic in accordance with the previously described strategy. Supply louvers within the inner isolation zone were either sealed or deflected on the basis of the test condition. For the control-off test condition (Condition 1), the HEPA unit was not activated and the room HVAC supply and exhaust were unaltered. Time constraints prevented switching between the original cloth and plastic curtains for the respective control conditions. Since the original curtains had excess open area relative to the floor-to-ceiling plastic curtains, the plastic curtains were retracted to a gap of approximately 3 feet (which varied by room and inner zone geometry) in an attempt to simulate the open area conditions between the patient and the remainder of the patient room under the control-off test condition.

To facilitate controlled airflow into the inner isolation zones for the control-on test conditions, each curtain was retracted to create an entrance gap into the inner isolation zone. This gap provided a path of least resistance to pull clean air into the inner isolation zone and toward the space occupied by a bedside healthcare worker. A qualitative “Curtain Gap Determination Protocol” was conducted, using a handheld smoke generator (*Cumulus Air Flow Indicator*, Draeger Safety Inc., Pittsburgh, PA, or *Wizard Stick*, Zero Toys, Inc., Concord, MA) to verify directional airflow into and within the inner isolation zone. For this test, smoke was released outside the full height of the gap to verify consistent (from floor-to-ceiling) negative airflow into the inner isolation zone. A second component to the smoke test included an evaluation of the smoke streamlines after it entered the inner zone. Curtain gap width and height were adjusted for each control-on test condition until smoke streamlines revealed an inward airflow path across the upstream healthcare worker position, across the patient’s head position, and into the HEPA filtration unit’s inlet.

A medical compressor and discharge tubing were placed on or near the patient bed to facilitate nebulizer (source) placement. Power to the compressor was provided by an extension cord leading out to the corridor to allow remote starting/stopping of the nebulizer. Nebulizer cup(s) were prepared according to the previously identified aerosol generation protocol and placed on the patient bed, adjacent to the mannequin mouth position, and connected to the compressor discharge tubing. After the first field survey, the source was increased from one to two nebulizers

operating simultaneously in order to increase room concentrations and decrease the impact of potential background aerosol.

Grimm aerosol spectrometers were programmed to record aerosol counts on a one-minute average and placed at the following positions: (1) patient chest vicinity; (2) healthcare worker positions at approximate breathing zone height (BZH) along both sides of bed; (3) directly outside the entrance to the inner containment zone; and (4) additional sample points, representing the center of the patient room and the adjacent patient area. Depending upon equipment availability and zone configuration, a sample position near the patient's feet was also collected. The zone-within-zone configuration schematic in Figure 12 indicates the dosing and sampling positions.

Ventilated Headboard: This was configured to serve a single patient bed within a single-patient room (Figure 13). As with the zone-within-zone configuration, the "patient" was represented by a life-size mannequin placed in the bed and covered with a hospital blanket.

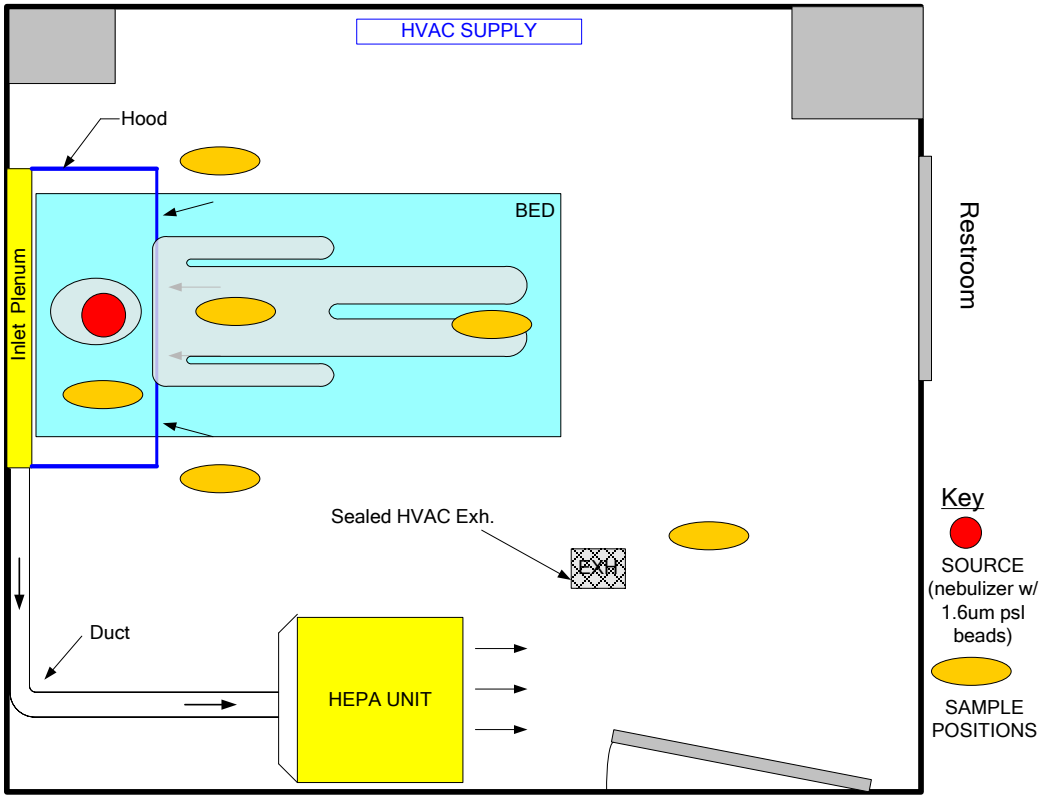


Figure 13. Example schematic of LEV positioning and equipment locations for a ventilated headboard expedient isolation configuration.

The ventilated headboard configuration used a semi-enclosing containment zone that consisted of the ventilated headboard LEV system and a retractable hood with open front. The hood extended away from the ventilated headboard and out over the patient's head and upper torso region. The hood frame was constructed with 1-

in-diameter schedule 40 water pipe and elbow fittings obtained at a home improvement store. The hood itself was made of medium weight (3.5- to 4-mil) plastic sheeting, such as that used for a paint drop cloth. The HEPA filtration unit was a portable model with a ducted inlet design. This unit was consistent with the type used during asbestos abatement or for dust control during construction/remodeling activities within healthcare settings. The HEPA unit was connected via a metallic-faced flexible 6-in-diameter duct to the LEV hood that served as a ventilated headboard. By design, the ventilated headboard was intended to pull room air uniformly into the hood, across the patient's head (the source) and into the exhaust/filtration system for cleaning and subsequent return to the patient room.

The ventilated headboard and hood required compatibility with the size and operation of the hospital bed. The hospital beds encountered in this study were consistently sized, measuring 42–44 inches in width, depending upon rail design. Some required an additional 2 inches of width (1 inch per side) in order to move the rails between the raised and lowered positions. Operational incline tests revealed that a hood height of 2 ft was consistently sufficient to allow adjustment of the bed incline up to approximately 45 degrees and was sufficiently high so as not to obstruct visual access to the television or to the faces of bedside visitors. Because of the similarity in bed dimensions and operation across the individual testing locations, the same headboard dimensions were used at each location.

The ventilated headboard measured 2 ft by 4 ft, and its frame was constructed with either 2- by 4-in or 1- by 4-in pine lumber. The back was made of ¼-in hardboard. Two air conditioning filters (2 ft by 2 ft by 1 in) were mounted to the front of the hood by a retaining track made of vinyl siding j-channel trim. A piece of 2-in-wide duct tape sealed the center seam shared by the two filters. In addition to performing as prefilters to extend the life of the HEPA filter, the inlet filters served to distribute the pressure differential across the hood face, promoting evenly distributed flow velocities.

A sheet metal (4-in by 10-in) residential HVAC register boot that transitioned into a 6-in-round duct take-off was mounted into the center bottom of the hood frame. This enabled connection to the 6-in flexible duct leading to the HEPA unit. This duct was routed along the room perimeter to avoid tripping hazards. All duct connections were further supported with duct tape. Two stilts, made with 1-in by 4-in lumber and attached to the sides of the headboard frame, were used to support the weight of the headboard and to determine its height. The back of the headboard was tethered to the wall to prevent tipping or lateral movement.

The bed height was set so that the top of the mattress was about 3 ft above the floor. The original bed headboard was easily removed to reduce interruptions to the desired airflow patterns. The bottom of the ventilated headboard was set just above the bed mattress. The hood frame was attached to the top of the ventilated headboard and extended outward over the upper torso region of the mannequin, with the bed making up the fourth plane of the enclosure. This design allowed the HEPA unit to draw air into the partial enclosure at mid-torso, across the mannequin's breathing zone (and the source), into the ventilated headboard, and

through the duct and HEPA filtration unit for air cleaning, all while maintaining healthcare provider access to the patient. The plastic sheeting, with its perimeter edges secured with packing tape, was draped over the frame and hood combination. Figure 14 shows a photograph of the ventilated headboard configuration with hood, mannequin, and sampling equipment in place at one of the field locations.

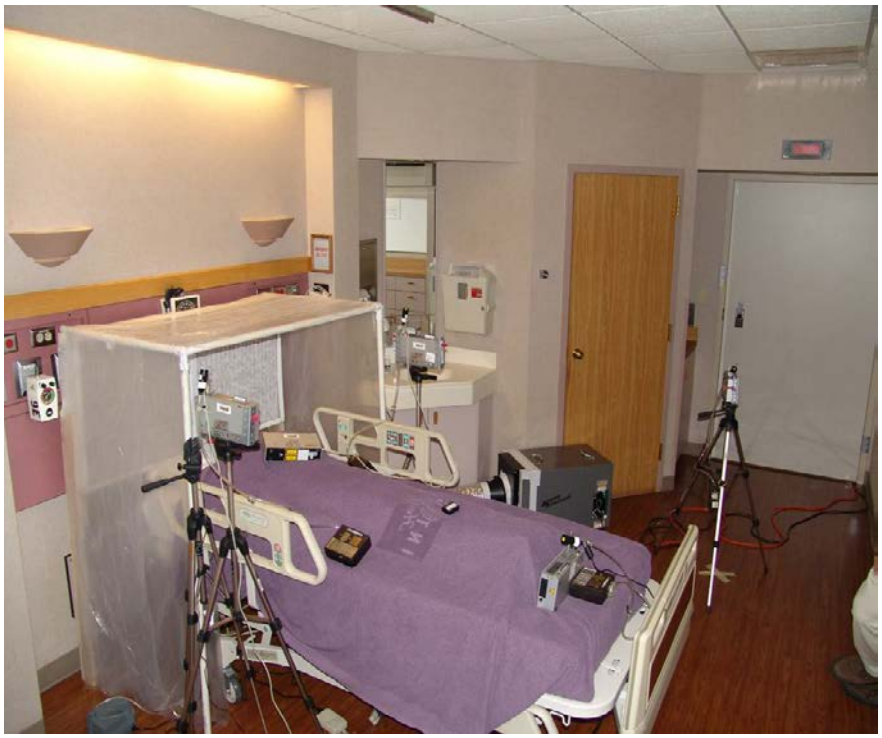


Figure 14. Photograph of ventilated headboard configuration as constructed for field research at the INTEGRIS Baptist Medical Center, in Oklahoma City, OK.

The flow rate through the HEPA filtration unit was adjusted with the HEPA unit's variable-fan-speed controller. The criteria used to identify a desired flow rate were (1) a targeted minimum flow rate of 12 ACH based on the overall room volume and (2) a minimum average velocity into the hood of 30 fpm in order to reduce the interruption potential of room air currents. To facilitate remote activation without room entry, the power to the HEPA unit was supplied by an extension cord that led out to the corridor.

In order for the hood to work effectively at the lower flow velocities, a critical design feature was the depth of the hood. These depth settings were determined with a handheld smoke generator (*Cumulus Air Flow Indicator*, Draeger Safety Inc., Pittsburgh, PA, or *Wizard Stick*, Zero Toys, Inc., Concord, MA) and a Hood Depth Determination Protocol. For this protocol, the HEPA unit was activated at the previously determined flow rate and smoke was released within the vicinity of the patient's breathing zone, across the entire hood cross-sectional area. During the smoke release, the hood depth was slowly shortened until the first evidence of smoke escape occurred, and then it was slowly lengthened until no more escape

was visible. This was repeated three times until a minimum hood depth (D_0) equal to the minimum hood depth where smoke escape was not visible could be determined. For purposes of the experimental protocol, two hood depths were selected, D_0 and D_0 + 8 in. To facilitate the evaluated research conditions, the hood's upper side rails were constructed with removable inserts to enable quick and consistent switching between the D_0 and D_0 + 8-in hood depths.

During control-on test conditions, HVAC exhaust grilles were sealed with tape and plastic in accordance with the previously described strategy. Supply louvers within the inner isolation zone were partially deflected if smoke tests revealed interrupting airflow in the vicinity of the hood. For the control-off test condition (Condition 1), the HEPA unit was not activated, the room HVAC supply and exhaust were unaltered, and the hood was rolled back off of the hood frame.

Medical compressors and nebulizers were used for surrogate source generation in the same manner as that described for the zone-within-zone configuration. Power to the compressors was provided by an extension cord leading out to the corridor to allow remote starting of the nebulizer. Grimm aerosol spectrometers were programmed to record aerosol counts on a one-minute average and placed at the following positions: (1) patient chest vicinity; (2) healthcare worker positions (approximate BZH) along both sides of bed; (3) open center of patient room; and (4) at the mannequin's feet, near the foot of the bed. Aerosol sampling and dosing positions are shown in the ventilated headboard configuration schematic in Figure 13.

Experimental Procedure

Both the zone-within-zone and ventilated headboard test configurations were evaluated for one control-off and two control-on conditions. For each configuration, this group of three conditions constituted one "block" of conditions. The conditions were randomly applied within each block. The randomization order was determined with use of an online random number generator developed by Dr. Mads Haahr (Trinity College, Dublin, Ireland) and located at www.random.org. Two rules applied to the random number output: (1) within a block, a condition may only appear once, and (2) once an order of test conditions was selected, that same order could not be used a second time. An initial study was conducted in which six blocks were conducted within the same room at a hospital test site. The data from this study provided important information regarding block-to-block sample variability. This information was used to assist in planning the follow-on field studies, namely by identifying the number of blocks required (based on sample variability) to obtain reasonable confidence limits around the estimated airborne concentration reductions at the various sampling positions.

Grimm aerosol spectrometers were activated and allowed to operate for a warm-up period of at least 30 minutes prior to the initiation of data collection. Calibrated air sampling pumps, with 25-mm mixed cellulose ester (MCE) filters/cassettes, were positioned adjacent to aerosol spectrometer sampling positions. (This step evolved following the first two field studies and will be discussed in more detail later in this chapter.) The filters allowed average particle concentrations to be calculated from

the sampled air volume and the number of particles collected on the filter, as determined by microscopy, for comparison with Grimm concentration estimates. Temperature/humidity loggers were placed within the patient room, in the corridor near the patient room entry, and in an adjacent patient room on the same HVAC supply system (if possible).

Patient Source Generation (Order of Operation)

- The HEPA systems were activated during room setup.
- The test configuration was set up according to the randomly ordered test condition appropriate for the experimental block. In addition to control-on test conditions, control-off test conditions were run to allow comparison of particle counts at the monitored positions with the same location measurements observed during the room's control-on condition(s). For all test runs, the patient room door was closed and the gap at the door's bottom was sealed with painting tape. For control-off test conditions, the containment boundaries were removed and the filtration equipment was deactivated.
- All aerosol spectrometers were placed on pause, internal memory was cleared, date/time settings were synchronized, and the machines were set for sampling at 1-min averages and placed on standby.
- The nebulizer cups were prepared according to the aerosol generation protocol and positioned with their output near the mannequin mouth position.
- Aerosol spectrometers and air sampling pumps were activated, the patient room was quickly exited, and the patient room door was closed and sealed along its perimeter with tape.
- The HEPAs were allowed to run for a period of 15–25 minutes (longer periods were selected following "control-off" test conditions), to reduce aerosol counts generated during setup activities.
- If the block condition was a control-off test condition, then the HEPA was deactivated by unplugging its extension cord in the adjacent corridor and allowing 10 additional minutes for background count stabilization.
- The nebulizers were activated and source generation was initiated by plugging in the appropriate extension cord (in corridor).
- After 25 minutes of source generation the nebulization was stopped, and 5 to 10 minutes of post-nebulization sampling was conducted to monitor decay trends.
- With the HEPA unit still activated, the patient room was reentered and the aerosol spectrometers and air sampling pumps were stopped.

Data Collection and Management

Physical parameters (room dimensions, HVAC supply, and exhaust locations) were logged for each test site and a room schematic was developed. A flow-capture hood (AccuBalance Air Capture Hood, Model 8371, or Alnor Electronic Balometer, Model APM 150, both from TSI Incorporated, Shoreview, MN) was used to establish room HVAC supply and exhaust volumes both before and after any modifications and to verify flow rate through the HEPA filtration systems. A hotwire anemometer (Airflow

Meter 8386A, TSI, Inc., Shoreview, MN) was used to measure air velocity into the inner containment zone. An electronic manometer feature on the same instrument was used to measure the pressure difference across the curtain boundary at the first survey site. Documentation of start and stop times and other experimental observations were manually recorded for each trial.

The predominant data evaluated for containment performance were particle count data from real-time light-scattering aerosol spectrometers (Grimm Dust Monitors, Models 1.10x, Labortechnik GmbH and CoKG, Ainring, Germany). For the purposes of this research, the size range of interest was that which encompassed the size of the source microspheres used in the nebulizer. The spectrometers logged the count data on an internal memory card in an American Standard Code for Information Interchange (ASCII) text tabularized format. The logged data were downloaded from the Grimms onto a portable computer using Grimm proprietary software and imported into Microsoft Excel for storage and cleaning (elimination of unwanted size ranges and extraneous data points logged during periods before/after actual test period).

Temperature and humidity data were collected using HOBO H8 Pro Series loggers (MicroDAQ.com Ltd, Warner, NH) programmed to log temperature and humidity measurements once every 5 minutes (sample frequency was once every minute at the first field site). In this setting, they could be positioned and allowed to collect data throughout the entire experimental period. Upon conclusion of each field study, the loggers were downloaded to a notebook computer. The temperature measurements within the patient room were subsequently evaluated to determine if the operation of the HEPA filtration units appeared to affect overall room comfort conditions and, if so, to compare the altered conditions with ASHRAE's environmental design recommendations (temperature range of 70–75°F) for human comfort in hospital patient rooms [ASHRAE 2003c]. When patient room temperatures were elevated, analysis of corridor and adjacent room temperatures provided insight as to whether the elevated temperatures were HEPA-related or perhaps related to the building/HVAC system operations.

Data Analysis

For a block of test runs, the objective was to compare the generated aerosol concentration counts observed during the control-on test conditions with those observed under control-off test conditions. The control-on test condition (conditions #2 and #3) data held much smaller particle count values than those observed during the control-off condition (condition #1), and the control-on conditions tended to result in data that were right-skewed. Since the control-on data were to be compared (using ratios) with control-off data, all the particle counts observed at the various test positions were log-transformed and the geometric means determined for the respective trials. The control-on conditions #2 and #3 were then compared with the uncontrolled condition #1 through a ratio of geometric means (gmean), which were presented in this form:

$$\text{Geometric Mean Reduction Ratio} = (\text{gmean1} - \text{gmean}x)/\text{gmean1} \text{ for } x = 2, 3.$$

Additional statistical analysis was conducted with use of SAS Proc Mixed (SAS Version 9.13, SAS Institute Inc., Cary, NC) to determine the 90 percent confidence limits on the geometric mean reduction ratio (GMRR). This model provided the standard error value, based upon the combined variance from the random effects, to be multiplied by the appropriate t-statistic (based on the model's assigned degrees of freedom) and resulting in a reduction ratio lower limit at $\alpha = 0.10$. The decision not to investigate/report lower limits for $\alpha < 0.10$ was deemed reasonable on the basis of compounding variability associated with aerosol generation, aerosol measurement, and sample placement, as well as the inherent variability associated with ventilation control systems that contain a human interaction component. On the other hand, the severity of the potential contaminant necessitates some rigor in the performance estimates of a selected design; thus, lower bound limits for $\alpha > 0.10$ were not evaluated.

For a given block of data at a given sample location, 26 data points were evaluated for analysis in the following manner:

1. The mean of the five minutes (5 counts) of data preceding the minute in which nebulization began was calculated as a background correction value (BCV).
2. The minute logged as the beginning of nebulization (t_0) was not used for analysis because it was uncertain how much of this minute's sample period actually included source nebulization time.
3. Data associated with the five minutes following t_0 were considered "transitional data" and ignored to allow time for noncontrolled aerosol to distribute throughout the room.
4. The BCV from step one was subtracted from each of the next 15 particle counts (minutes 6–20 following t_0) observed following the transitional data period. Resulting values below zero were reset to zero. These 15 values were the background (BG)-corrected data values used for subsequent analysis.
5. A small baseline shift of 0.03 was added to each of the BG-corrected values to remove any computational problems associated with log-transformation of zero values.
6. The natural logarithm was taken for each of the 15 values identified in step 5 and the mean of these values was calculated, resulting in a single BG-corrected, baseline-shifted, log-transformed data point representing the estimated particle count associated with the individual test run.
7. The data from step 6 were coded according to position, block, and test condition, and a single average was determined for each condition-position pairing. For each sample position, the reduction determined to result from each of the control-on conditions (#2 and #3) was calculated with the GMRR formula as described above.
8. Additional statistical analysis, using the representative data points from step 6, was conducted with SAS Proc Mixed to identify the predictive model providing the lower 90 percent confidence limit reduction ratios for the examined test conditions. Thus, the reduction could be said, with 90 percent confidence, to be at least as great as the lower confidence limit.

Once data from an initial test site were evaluated to determine the minimum number of blocks desired, the approach described above was repeated for the defined number of block repetitions at three additional healthcare facility locations of differing physical and HVAC operational design. Following completion of the field studies, the test conditions were evaluated for their performance in (1) containing airborne contaminant within the designated inner zone and (2) reducing healthcare worker exposures relative to that experienced under the no-control test condition.

Air Filter Sampling and Particle Counting

Following the first zone-within-zone field evaluation, suspicion arose that low levels of background aerosol originating from sources other than the nebulizer might have affected some of the observed particle counts. In most circumstances, and especially for sampling positions more proximate to the nebulizer source, these counts would be expected to be too low to impact the overall results. For sample locations more distant from the source and under control-on test conditions, even low-level contamination could impact the ability to document the highest levels of source aerosol containment. At the second field survey site, filter samples were collected for subsequent analysis with scanning electron microscopy (SEM). Unfortunately, results from this sampling effort were unobtainable when the preparation method used by the microscopist to fix and clear the filter media onto the slide appeared to have destroyed the PSL beads captured on the filter. Conversations with Drs. David Johnson and Robert Lynch at OUHSC revealed they were having similar problems with background aerosol and with greater impact due to the relatively dirty warehouse-based test environment used in their own research. Thus, they had opted to pursue an optical particle counting method instead of using the aerosol spectrometers. Initially, a 25-mm nonconductive styrene cassette with 0.8-μm–pore-size mixed cellulose ester (MCE) filter (Catalogue No. 225-3100, SKC Inc., Eighty Four, PA) was used to conduct the air sampling for this method; however, subsequent field tests used 25-mm-diameter, 0.8-μm-pore-size MCE filters preloaded in carbon-filled conductive polypropylene cassettes (Catalogue No. 225-321, SKC Inc., Eighty Four, PA), typical of those used for asbestos sampling. Through ongoing conversations and method development experiments by Johnson and Lynch, an eventual aerosol optical counting method was developed using a green fluorescent microsphere suspension with PSL microspheres of 1.9 μm mean diameter (Catalog No. G0200, Duke Scientific, Palo Alto, CA). With use of fluorescent microspheres of a known size in the source suspension, an optical filter could be employed with the optical microscope, which should limit the visible aerosol to primarily those that originated from the nebulizer. Thus, beginning with the third field survey, the source suspension formula for the hospital expedient isolation research was slightly modified by substituting the 1.9-μm (d_a = 1.95 μm) fluorescent PSL microspheres for the previously identified 1.6-μm PSL microspheres. The slightly larger test aerosol was still within the 1- to 3-μm size range of interest, and the 0.3-μm increase in aerosol diameter was sufficiently small that changes in airborne behavior were negligible (increased V_{TS} of only 0.33 cm/sec) and the Raabe-predicted singlet generation remained at 99 percent. Because any slight deviations in either behavior or generation would occur in both controlled and noncontrolled test conditions, there was no determined need to revalidate the aerosol generation protocol.

Personal air sampling pumps (Model 224-PCXR8, SKC Inc., Eighty Four, PA) with filter cassettes attached were co-located with aerosol spectrometer sampling locations; however, since this method was evolving as the field studies transpired, the number and locations of the filter sampling positions often varied by field study. The filter samples were analyzed by Dr. Lynch at OUHSC using a fluorescent microscope and an optical counting method recently discussed in another publication [Johnson and Lynch 2008]. In this method, each low count filter was analyzed via a total scan and manual count of the entire filter. For more densely loaded filters, the total count was estimated by a random field manual count technique.

For a given field study, the filter count results were organized according to sample position, block, and test condition. Though the actual dosing periods were consistent, the nature of the protocol resulted in some sample periods in which air was drawn through the filter for longer periods than in others. This was primarily true for the no-control test conditions. To address the discrepancy, the raw particle counts were divided by their corresponding airflow that was sampled only during the dosing period, in order to get a "dosing concentration." The "dosing concentration" was the value subjected to performance analysis. The resulting concentration values were log-transformed and the geometric mean values were calculated for each test condition, as was done with the Grimm data. Since some of the field study results included filter counts of zero fluorescent spheres, the baseline was once again shifted by 0.03 to avoid difficulties with the log transformation of zero values. For each sample position and test condition, the mean of the log-transformed values was determined and the exponentiation of that value was used to obtain the geometric mean of the baseline-shifted data. Similar to the aerosol spectrometer data, the exposure reduction determined to result from each of the control-on conditions (#2 and #3) was determined by the GMRR.

Chapter III

Results

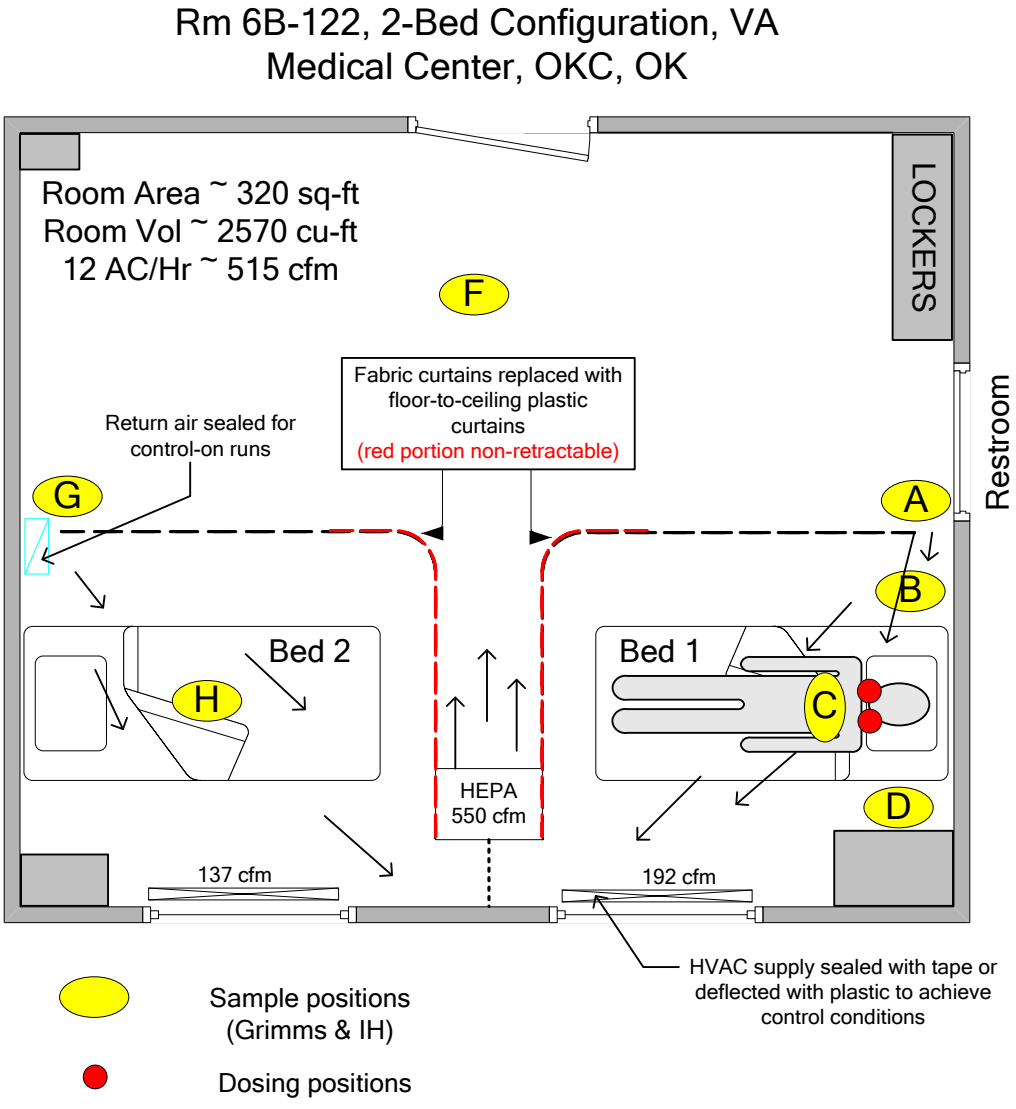
Two expedient AII configurations were evaluated in each of four hospitals for a total of eight field studies. The field testing procedures followed those identified in Chapter II, with occasional modifications to accommodate facility and HVAC design issues. Site-specific details and corresponding results are described below, organized by location.

Oklahoma City Department of Veterans Affairs Medical Center

The Oklahoma City Department of Veterans Affairs Medical Center (VAMC) was a 169-bed facility with authorization to expand up to 245 beds. Located on the University of Oklahoma Health Sciences Center Campus in Oklahoma City, Oklahoma, this was a Clinical Referral Level III facility and a teaching hospital, capable of providing a full range of medical, psychological, and related services to eligible veterans.

Zone-within-Zone, Two-Patient Configuration

The zone-within-zone configuration study at VAMC was the first of the expedient isolation field studies. The patient room had a floor area of approximately 320 ft^2 and an approximate room volume of 2,570 ft^3. The original room design accommodated three patients, with no provisions for airborne isolation. For the expedient isolation research, the room was converted (Figure 15) to hold just two expedient isolation patients.



NOTE: Sample position labeling differs from other sites, point E (not shown) was at filter inlet and was not used for analysis.

Figure 15. Schematic of zone-within-zone expedient isolation configuration at the VA Medical Center in Oklahoma City.

Configuration Setup: The zone-within-zone configuration was established according to the methodology prescribed in Chapter II. The freestanding HEPA filtration unit (Model NU-114, NuAire Inc., Plymouth, MN) was positioned equidistant between the footboards of the two patient beds, diagonally across from the respective entrances into the two inner zones. A photograph of the inlet side of the HEPA unit, with the vertical partition that separated the two inner zones, is shown in Figure 16.

Figure 16. Photograph showing the freestanding HEPA filtration unit positioned between the two inner isolation zones. The edge of the curtain was sealed to the HEPA unit, and a vertical partition equally divided the inlet to prevent migration between the two inner isolation zones.

HEPA Flow Rate Determination: Given an overall room volume of 2,570 ft^3, a HEPA filtration flow rate of 515 cfm was required to achieve the desired 12 ACH. Flow rate through the HEPA unit was adjusted with a variable-fan-speed controller, and a filtration rate of 550 cfm was obtained for the control-on test conditions.

Curtain gap determination: The Curtain Gap Determination Protocol was conducted to establish the entrance gap widths under the two control-on test conditions. The protocol revealed a consistent airflow into the inner isolation zone for curtain gaps up to 15 inches. When the gap approached 8 inches or smaller, the streamlines shot rapidly inward along the wall, resulting in turbulent mixing near the patient head and at the far side of the bed, away from the gap. When the gap approached 15 inches, the streamlines turned quickly toward the HEPA unit without passing over the healthcare worker position and the patient. On the basis of streamline observations, a gap of 10–12 inches was selected for the test conditions, with the wider gap selected under condition #3, when the inner zone's HVAC supply was sealed.

Center-line velocity measurements along the height of the curtain gap were collected for each of the control-on conditions. The 12-inch gap corresponding to test condition #3, with the inner isolation zone HVAC supply sealed, resulted in a mean inward velocity of 37.8 fpm (range, 25–48 fpm; n = 5). The 10-inch gap corresponding to condition #2, with the inner isolation zone HVAC supply open,

resulted in a mean inward velocity of 30 fpm (range, 7–45 fpm; n = 5). In addition, the electronic manometer function of the TSI VelociCalc was used to measure the pressure differential beneath the curtain for both the 10-inch and 12-inch gap positions. In both cases, the pressure differential was less than the detection limit (0.001 in w.g.) of the manometer.

Experimental Procedure: Initial plans called for the preliminary completion of three blocks of test runs, with the three test conditions randomly applied within each block. Block-to-block sample variability from these blocks was to assist in determining the total number of blocks to conduct for this and subsequent field studies. However, results from an initial test run revealed widely erratic reporting of aerosol counts, especially among the newest aerosol spectrometer models. A detailed series of troubleshooting investigations was initiated with interaction from the equipment representative in Georgia and the instrument design engineers in Germany. After several days of troubleshooting experiments and examination of data output, an upgrade was made to the manufacturer's equipment operations software. Five new Grimm aerosol spectrometers were obtained on loan, resulting in a total of eight spectrometers of the same model (1.108ss) available for the experimental setup. All of the units were operated with the manufacturer's updated software (1.177 version 3.1, Grimm Technologies, Inc.). Two additional changes were made to the field evaluation protocol. The first was due to higher-than-expected background aerosol counts within the 1- to 2-µm size range. Thus, the number of nebulizers used to generate the source aerosol was increased to two. One nebulizer was placed on each side of the mannequin's mouth, with their output nozzles oriented at an angle to intersect at an imaginary point just beyond the mannequin's jaw. The second change resulted from concerns about potentially disrupting air currents originating from the HVAC supply louver. To address this concern, one of the "control-on" test conditions was modified from an *HVAC-open* setup to an *HVAC-open-but-deflected* setup, as described previously in Chapter II.

Following the loss of four days of experimental time due to instrument troubleshooting, the hospital unexpectedly requested to regain use of the ward where the experiments were being conducted. As a result of this request, conducting a preliminary block-to-block variability study was no longer possible. The decision was made to work as fast as possible within the remaining time allotted to complete a series of six experimental blocks for just the zone-within-zone configuration. The use of six blocks allowed each possible permutation of the applied order of the three test conditions to receive a single evaluation. Thus, if there were any order-specific influences upon performance results, it would be equally represented within the data. Each block took between four and five hours to conduct. The sequence of operations for the blocks followed that previously identified in the protocol; however, the Grimm instruments were rotated to new position assignments to reduce potential instrument-associated bias upon a single sample location. There were no air filter samples collected at this site for subsequent optical analyses.

Table 3. Geometric mean reduction ratios (GMRRs), by sample position and test condition code, from Grimm aerosol spectrometer results in the zone-within-zone expedient isolation field study at the Oklahoma City VA Medical Center.

Position Description	Location Label	N	GMRR Test Condition 2	GMRR Test Condition 3
Outside inlet 1 (source patient)	A	6	0.998	0.999
HCW position (upstream)	B	6	0.134	0.163
Patient's chest*	C	6	n/a	n/a
HCW position (downstream)	D	6	-0.767	-0.800
Center of outer zone	F	6	0.999	0.999
Outside inlet 2 (nonsource)	G	6	0.993	0.997
Center of Bed 2 (nonsource)	H	6	0.987	0.997

* Position C, patient's chest, was not evaluated because of its position within the path of the captured contaminant streamline toward the HEPA unit.

Note:
HCW = health care worker; location labels are shown in Fig. 15.

Performance Ratio: Table 4 shows the number of performance ratio determinations that were available at each sample position, as well as the GMRRs based upon the Grimm particle count data. Sample positions are described in Table 4 and shown in Figure 15.

Table 4. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected in the ventilated headboard expedient isolation field study at the Oklahoma City VA Medical Center.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
HCW at right of source	A	6 6	0.997 0.999	0.996 0.999
HCW at left of source	B	6 6	0.997 0.999	0.996 0.999
Patient's chest	C	6	1.0	1.0
Foot of bed	D	6 6	0.995 0.999	0.997 0.999
Center of room	E	6 6	0.997 0.999	0.996 0.999

Temperature Measurements: Temperature/humidity loggers were placed at each of the two bed positions, in the center of the patient room and in the hall corridor. A downloading error limited the recoverable data from these loggers to a single day's worth of data, recorded at one-minute intervals and covering a single block of test runs. A review of the three patient room temperature data logs revealed all temperatures within or below ASHRAE design temperature guidance; thus, only the patient room temperature log was evaluated. All three mean temperatures fell within 69±1°F and had a combined range of 67–72°F. A graph of temperature data logged at the source bed position is shown in Figure 17. The hatched area identifies the ASHRAE recommended design temperature range of 70–75°F. The three columns represent known fan/door conditions corresponding to the three test trials evaluated during an individual block of test data. Though the door was generally left open and the HEPA fan was operating during the setup portion of the day, the precise timing of door position and HEPA fan status was not reported for these periods. However, the door positions were known to remain closed during the three test trials, so combined with the HEPA status logs from the individual test conditions, these periods can be evaluated. The slope during the first trial remains flat, revealing either no affect upon room temperature or one that was coincidently offset by the room HVAC system. The downward slope during the HEPA Off condition, immediately followed by an upward slope during the subsequent HEPA On condition, could possibly reflect a slight influence of the HEPA fan operations; however, even here, the fluctuations are within a narrow 2-degree window, and room temperatures stayed well within the ASHRAE recommended guidance.

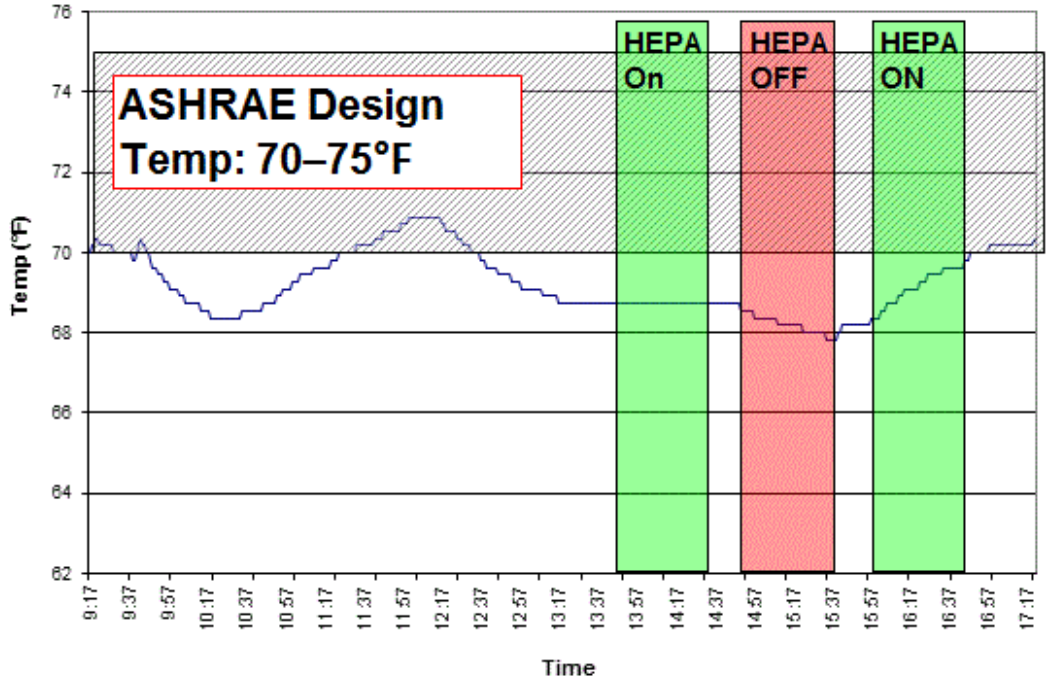


Figure 17. Graph of temperatures logged during one day of the zone-within-zone field study at the VA Medical Center in Oklahoma City.

Ventilated Headboard, One-Patient Configuration

The ventilated headboard configuration study at VAMC was conducted about 15 months after the zone-within-zone study. The available patient room was a single-patient room, with an anteroom, that was designed to be placed into negative-pressure isolation mode on an as-needed basis. For the purposes of this research, the negative-pressure mode was not used; the door to the corridor remained closed and the door between the anteroom and patient area remained open to neutralize any small pressure differentials between the patient room and the anteroom. The patient room (Figure 18) had an approximate floor area of 120 ft^2 and an approximate room volume of 970 ft^3.

Configuration Setup: The ventilated headboard configuration was established according to the methodology prescribed in Chapter II. To minimize disrupting supply air currents at the hood inlet, the HVAC supply louver immediately above the patient bed was deflected, with plastic sheeting as a baffle, toward the wall furthest from the head of the bed. The HEPA filtration unit (Model PAS600, Abatement Technologies Inc., Suwanee, GA) used for this isolation configuration was of a ducted inlet design. With the rails locked into the upward (safety) position, the bed (width, 3 ft 8 in) fit effectively within the 4-ft-wide hood. The ventilated headboard and hood frame, with the hood removed, are shown in Figure 19.

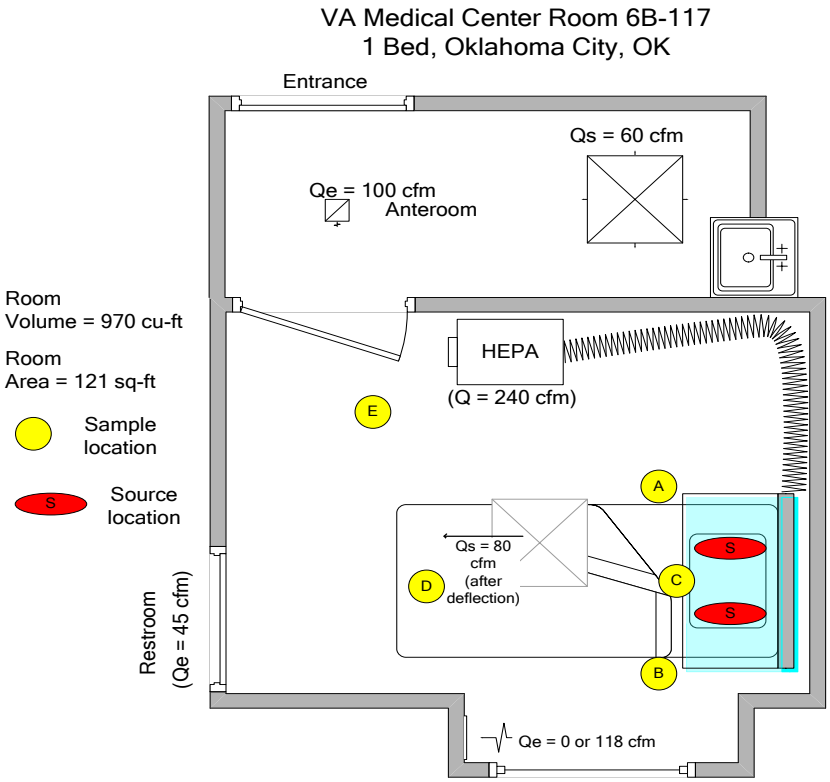


Figure 18. Schematic of ventilated headboard single-patient configuration evaluated at the VA Medical Center in Oklahoma City.

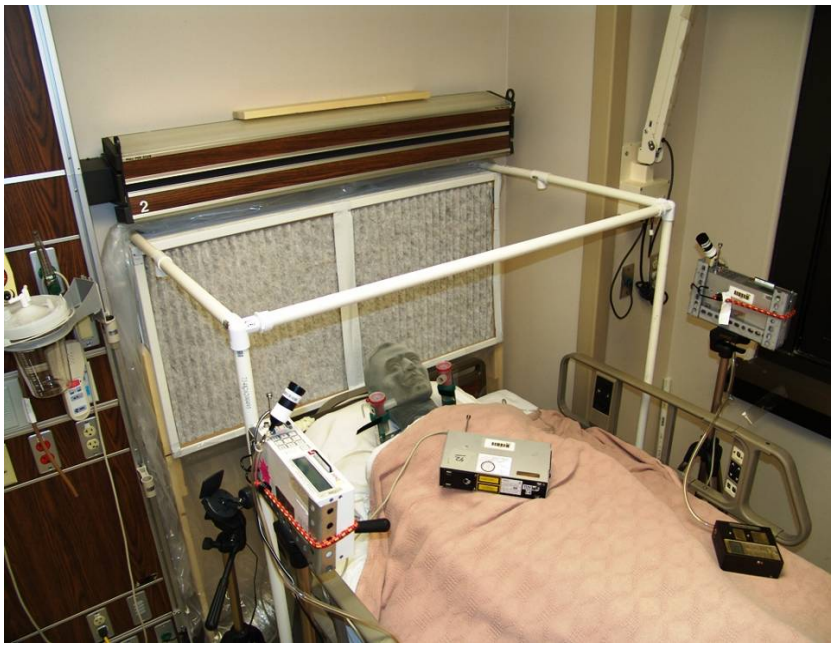


Figure 19. Photograph of ventilated headboard and hood frame as constructed for research at the Oklahoma City VA Medical Center.

HEPA Flow Rate Determination: Given an overall room volume of 970 ft^3, a HEPA filtration flow rate of 195 cfm was required to achieve the desired 12 ACH. However, a desired minimum airflow rate through the HEPA filter unit of 240 cfm was targeted in order to provide a 30-fpm average flow velocity into the 8-sq-ft open area of the hood. The flow rate through the HEPA filtration was adjusted with a variable–fan-speed controller, and a filtration flow rate of 240 cfm was achieved, resulting in a HEPA-filtered airflow of just under 15 ACH.

Hood Depth Determination: The Hood Depth Determination Protocol was used to establish the two hood depths (D_0 and D_0 + 8 in) to be evaluated under the two test conditions. At the Oklahoma City VA Medical Center, these values were 2 ft 4 in and 3 ft, respectively, and the appropriately sized hood side rail inserts were made to facilitate quick and consistent switching between the two hood depths.

Experimental Procedure: The VAMC was the third field study location to evaluate the ventilated headboard expedient isolation approach. At this point in the field research activities, the determination had been made to conduct six blocks of three test conditions, with each of the three conditions randomly applied within each block.

Five aerosol spectrometers were used for sample collection and distributed as shown in Figure 18. All five spectrometers were of the same model (Grimm Technologies Model 1.108), and all were set up and downloaded with Grimm's 1.177 version 3.1 software. The experimental sequence of events for the blocks followed that previously identified in the protocol, to include the placement of industrial hygiene (IH) sampling trains fitted with 25-mm MCE filters (0.8-μm pore size) and calibrated to a flow of 1.5 Lpm. The IH sampling trains were co-located with Grimm spectrometer sampling positions A, B, D, and E (Figure 18), and sufficient filter medium was available to allow sampling for each trial run within each block. Both Grimm spectrometers and the IH sampling trains were rotated to a new sample position prior to initiation of each new block. This helped to evenly distribute any unknown instrument error or bias.

Performance Ratios: Table 5 shows the number of performance ratio determinations that were available for each sample position, as well as the GMRRs for the evaluated conditions. Data from both the aerosol spectrometers and the IH filter samples are included in the table.

Table 5. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected in the ventilated headboard expedient isolation field study at the Oklahoma City VA Medical Center.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
HCW at right of source	A	6 6	0.997 0.999	0.996 0.999
HCW at left of source	B	6 6	0.997 0.999	0.996 0.999
Patient's chest	C	6	1.0	1.0
Foot of bed	D	6 6	0.995 0.999	0.997 0.999
Center of room	E	6 6	0.997 0.999	0.996 0.999

Temperature Measurements: Temperature/humidity loggers were placed on the patient bed, in the anteroom, and in an adjacent patient room, and measurements were logged at 5-minute intervals over the six-day field survey. This particular field survey was conducted in mid-August, when outdoor temperatures in Oklahoma consistently exceeded 100°F. The high outdoor temperatures sometimes challenged the HVAC system's ability to keep the patient rooms within ASHRAE's 70–75°F design temperature range, as reflected in the temperature data summary shown in Table 6. No patients were in this wing during the field study, so the temperatures do not necessarily reflect actual operating conditions for patient areas. The lower temperatures observed within the anteroom were believed to result from this area's lack of solar load from exterior walls and window surfaces.

Table 6. Summary of temperature data logged during ventilated headboard expedient isolation field study at the VA Medical Center, Oklahoma City, OK.

Temperature in °F	Mean	Min	Max
Patient room (n = 1520)	75.89	71.96	79.16
Anteroom (n = 1522)	72.66	70.88	75.74
Adjacent room (n = 1522)	75.50	71.60	79.16

A line graph of temperature data logged at the source bed position during one day of the field study is shown in Figure 20. The hatched area identifies the ASHRAE

recommended design temperature range of 70–75°F. The six color-shaded columns represent periods of known fan/door conditions that correspond to the six test trials (two blocks) evaluated that day. The six test trials generally occurred during the hottest portion of the day, when room temperatures exceeded the 75°F upper limit of the ASHRAE design guidance; however, the slope of the line graph was downward in all four of the test trials in which the HEPA was operated. This indicates that any added heat originating from the HEPA fan was negligible in comparison to the room's HVAC temperature controls.

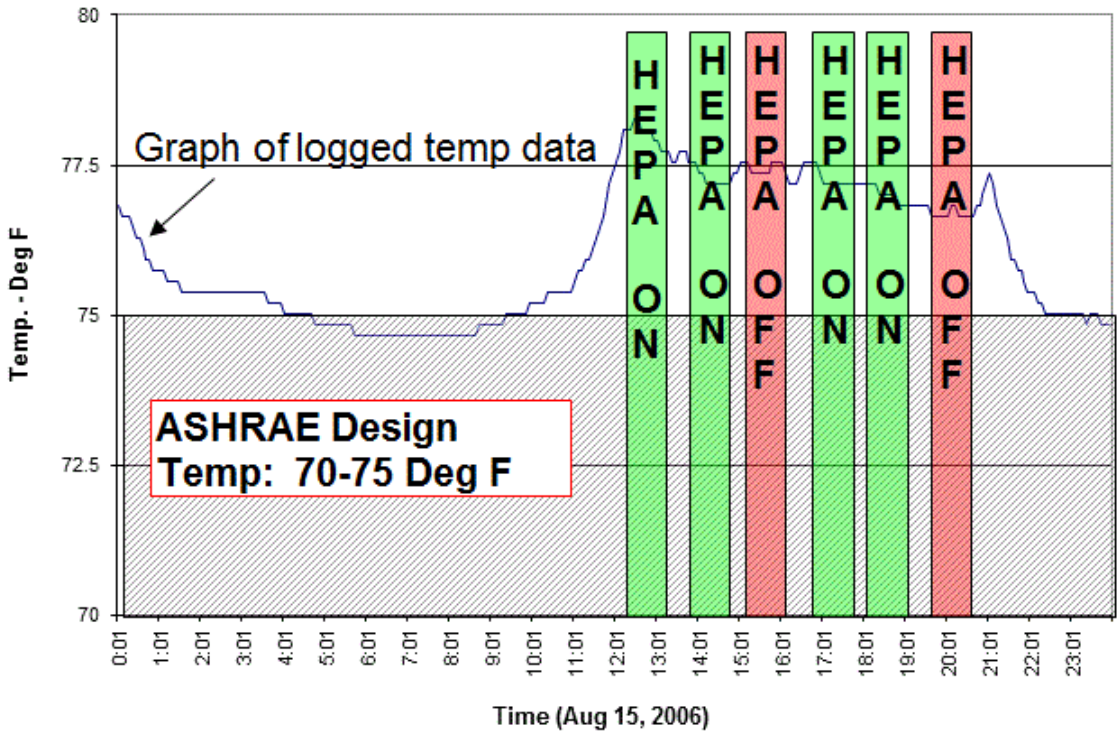


Figure 20. Graph of temperatures logged in the patient room during one day of the ventilated headboard field study at VA Medical Center in Oklahoma City.

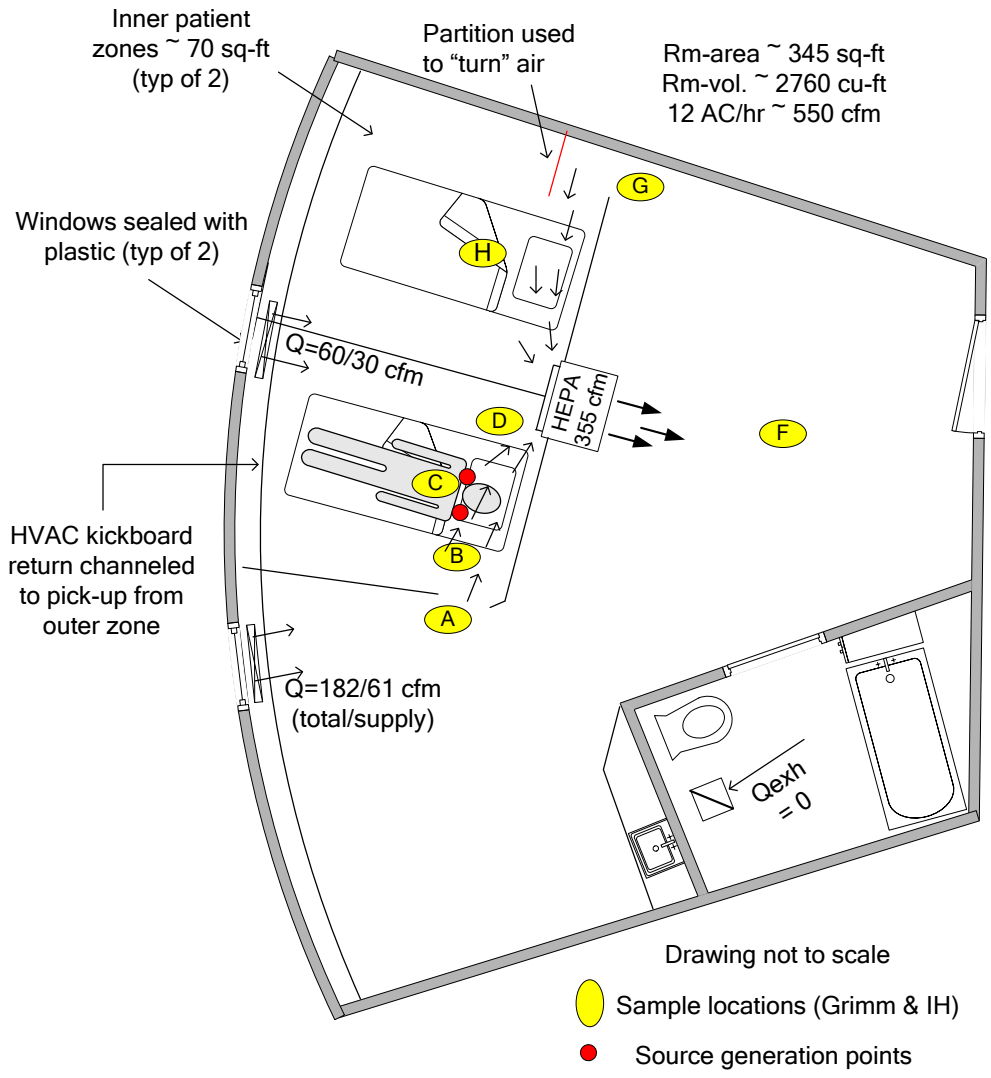
Central Kansas Medical Center, Great Bend, KS

Central Kansas Medical Center (CKMC) is in Great Bend, Kansas, which has a population of roughly 15,000 and is 120 miles northwest of Wichita. At the time of the study, CKMC was a 74-bed, regional acute care hospital serving an overall population of 60,000. The main footprint of the current facility was a six-story cloverleaf design executed in 1964. Additional construction has since provided office space, laboratories, and dining facilities. The CKMC was the primary facility of a two-campus operation, with the second campus located 20 miles away in Larned, KS. The CKMC facility included an intensive care unit, emergency room, Level II Nursery, full laparoscopic system, and fixed-site MRI and CT equipment. There were no engineered AII rooms within this facility. Procedures for AII involved the use of a portable freestanding HEPA filtration unit, which was placed near the window within the patient room and whose discharge was directed outdoors via a special window fitting.

Zone-within-Zone, Two-Patient Configuration

The zone-within-zone configuration study at CKMC was the second of the expedient isolation field studies. The multi-patient room had a floor area of approximately 345 ft^2 and a volume of roughly 2,760 ft^3. The room's floor space resembled a truncated pie shape, with the exterior windows located along the outer arc length and the entry door located within a narrower wall opposite the arc length. The room was designed to accommodate three patient beds, with no provisions for AII. For the expedient isolation research, the room was converted (Figure 21) to hold just two expedient isolation patients.

Rm 525, 2-Bed: Great Bend, KS



NOTE: Sample position labeling differs from other sites, point E (not shown) was at filter inlet and was not used for analysis.

Figure 21. Schematic of zone-within-zone expedient isolation configuration at the Central Kansas Medical Center, in Great Bend, KS.

The patient room's HVAC design utilized induction air units supplied by a low-volume, single-pass air supply that originated from a central HVAC unit. Within each induction unit, the supply air was released through a multi-nozzle supply plenum to induce recirculatory airflow into the bottom of the wall cabinet and past a heat exchanger, before the combined airflows exited through the top of the cabinet. The induced airflow into the cabinetry resulted in the entire kickboard along the outer wall serving as an inlet for recirculating airflow. For the expedient isolation configurations, the kickboard space within the inner isolation zones was treated like a return air grille in regards to the field protocol and sealed with tape and plastic. This forced the induction units to obtain all of their recirculatory air from the outer zone. Similarly, during test condition 3, when the inner zone HVAC supply was supposed to be closed, closure was not realistically feasible, so the HVAC supply air was routed to a release point outside of the inner isolation zone. In addition, there were two large double-hung windows built into the exterior wall. Both windows were also sealed with plastic and tape so as not to be a source of air pressure or ambient aerosol.

Configuration Setup: The zone-within-zone configuration was established according to the methodology prescribed in Chapter II. With the pie-shaped room and the use of the existing curtain tracks to establish inner isolation zones, the patient orientation was such that the head was positioned away from the outer wall. The curtain entrance gap and the freestanding HEPA filtration unit (HEPA-Care Model HC800F) were positioned on the same end of the isolation zone, away from the exterior wall, resulting in a side-to-side airflow across the mannequin's upper torso. The HEPA inlet on this unit was smaller and lower than that on the NuAire unit; thus, the bed height was adjusted so that the mattress height was consistent with the HEPA inlet (approximately 28 inches from floor to top of mattress).

For the inner isolation zone closest to the wall (containing sample position H), the side draft orientation required the installation of a floor-to-ceiling partition to "turn" the air as it entered the inner zone. Qualitative smoke tests conducted with a handheld smoke generator confirmed the effectiveness of this approach.

Figure 22 shows the interface between the HEPA filter and the plastic curtains, including the plastic curtain that bisected the HEPA inlet between the two inner isolation zones. A smoke test, underway at the time of the photograph, demonstrated that smoke released near the pillow area was pulled toward the HEPA inlet.

Figure 22. A photograph showing the HEPA filter unit's inlet relative to the source bed pillow position, during a qualitative smoke test at Central Kansas Medical Center, Great Bend.

HEPA Flow Rate Determination: Given an overall room volume of 2760 ft^3, a HEPA filtration flow rate of 550 cfm was required to achieve the desired 12 ACH. Flow rate through the HEPA unit was adjustable with a variable-fan-speed controller, and a filtration rate of 550 cfm was achieved for the control-on test conditions. This was the maximum flow rate achievable through this HEPA unit in this configuration.

Curtain gap determination: The Curtain Gap Determination Protocol was conducted to establish the entrance gap widths under the two control-on test conditions. Gaps of 10–12 inches were again selected for the test conditions, with the wider gap selected for condition 3, when the inner zone's HVAC supply was routed to a release point outside of the inner zone.

Center-line velocity measurements into both of these gap widths were inadvertently not recorded in the log book. On the basis of a mathematical ($Q = V \times A$) examination of the HEPA flow rates and the entrance gap open area, if one assumed that virtually all the 275 cfm of makeup air entering the inner isolation flowed through the curtain gap, then the velocity through the curtain 12-inch gap would be expected to average about 34 fpm. For the 10-inch gap associated with Condition 2, the HVAC grille inside the inner isolation was open. This provided about 25 cfm of supply air into the inner isolation zone that did not have to flow through the curtain gap. The resulting calculated velocity through the 10-inch curtain gap was expected to average about 37 fpm.

Experimental Procedure: Delays in receiving all of the necessary equipment resulted in six blocks of experiments for the zone-within-zone configuration being conducted at this location. This allowed each possible permutation of the applied order of test conditions to receive a representative evaluation. The plan was for

analysis to be performed on the data from these blocks, and if additional blocks were deemed necessary for statistical power, they could be performed the following month, upon the researchers' return to CKMC for the ventilated headboard experiments. The sequence of operations for the blocks followed that previously identified in the protocol; however, individual Grimm instruments were rotated to new, unique position assignment after blocks one and four to reduce potential instrument-associated bias upon a single sample location.

Eight model 1.108 Grimm aerosol spectrometers were used in the experiments. Sample position E (not shown in Figure 21) was positioned at the HEPA filter inlet for potential use as a trouble-shooting sample. These data were not analyzed once it was determined that the experiments had proceeded successfully. This field study was the first location that included an attempt to collect IH filter samples for subsequent analyses. In this attempt, the anticipated analysis method was the use of scanning electron microscopy (SEM), and IH sampling trains were co-located at sample positions A and G for this purpose.

Performance Ratios. Table 7 shows the number of performance ratio determinations that were available at each sample position as well as the GMRRs based upon the Grimm particle count data. Sample positions are described in Table 7 and were previously shown in Figure 21. Results from the filter samples collected for SEM analysis were unobtainable. The preparation method used to fix and clear the filter media onto the slide appeared to have destroyed the PSL beads captured on the filter. Thus, there are no optical filter count results reported for this field study.

Table 7. Geometric mean reduction ratios (GMRRs), by sample position and control-on condition code, from Grimm aerosol spectrometer data obtained at Central Kansas Medical Center in the zone-within-zone expedient isolation field study.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
Outside inlet 1 (source patient)	A	6	0.998	0.993
HCW (upstream)	B	6	0.998	0.988
Patient's chest	C	6	0.761	1.00
HCW (downstream)	D	6	0.928	0.993
Center of outer zone	F	6	0.999	0.998
Outside inlet 2 (nonsource)	G	6	0.999	0.999
Center of Bed 2 (nonsource)	H	6	0.999	0.996

Sample Size Discussion: The data from the CKMC zone-within-zone field study were evaluated for determination of benefits derived from conducting additional test blocks. This analysis was completed as part of the planned overall data analysis with use of SAS Proc Mixed, which will be discussed in further detail in the next chapter. To evaluate the benefit of additional blocks, the potential impact of those blocks upon calculation of the model's standard error term was evaluated. In looking at the model's variance calculations (with an assumed end goal of determining simultaneous confidence limits), the estimate was based on a difference of two statistically independent terms (the difference became a ratio when it was exponentiated). Though independent, each term had a common variance, which was subsequently multiplied by 2 (since two terms). For the evaluated data set, the estimated variance (residual plus that associated with control variability over blocks) was 0.965. Multiplying by 2, dividing by the number of blocks (6), and taking the square root resulted in the standard error term of 0.567, associated with the difference of two means (control and no-control) at the same location, which was applied to the t-statistic quantile for each of the sample positions. If it was assumed that subsequent blocks would demonstrate the same variance as the previous six, then the benefits of additional blocks could be calculated. For example, adding a seventh block would result in a standard error term of only $([0.965 \times 2]/7)^{0.5} = 0.525$. Thus, to get a substantial reduction (i.e.

25% or greater) in standard error, several more blocks (at ½ day of field time per block) would have to be added. This was considered to be both time-restrictive and fiscally restrictive. In addition, because it was thought that the reduction due to the controls would be substantial relative to the observed standard errors, the use of six blocks, given the permutation advantages previously discussed, was deemed to be adequate, and the decision was made to continue forward with the goal of six blocks per field study.

Temperature Measurements: Temperature/humidity loggers were placed on the source patient bed (position C), on the nonsource patient bed (position H), in the center of the patient room (position F), and on the corridor wall outside of the patient room (position not labeled). Temperatures were logged at 5-minute intervals over the three days of data collection. Elevated outdoor summer temperatures appeared to challenge the HVAC system's ability to keep the patient room within ASHRAE's 70–75°F design temperature range, as reflected in the temperature data summary shown in Table 8. (No patients were in this wing during the field study, so the temperatures did not necessarily reflect actual operating conditions for patient areas.) The lower temperatures observed within the corridor were believed to result from this area's nonobstructed air pathway to actively occupied (and potentially better conditioned) areas of the hospital, plus the absence of a solar load originating from exterior walls and window surfaces.

Table 8. Summary of temperature data logged during zone-within-zone expedient isolation field study at Central Kansas Medical Center, Great Bend, KS.

Temperature in °F	**Mean**	**Min**	**Max**
Source patient bed (n = 666)	75.17	72.68	77.72
Nonsource patient bed (n = 667)	77.61	74.12	82.04
Center of patient room (n = 667)	74.81	73.22	76.82
On corridor wall (n = 666)	73.55	73.04	74.12

A line graph of temperature data logged at the source bed position during one day of the field study is shown in Figure 23. The hatched area identifies the ASHRAE-recommended design temperature range. The nine color-shaded columns represent periods of known fan/door conditions corresponding to nine test trials (3 blocks). The HEPA fan status and door positions were known during the nine test trials, so these periods could be evaluated. Six of the nine test trials generally occurred during the hottest portion of the day, when room temperatures exceeded the 75°F upper limit of the ASHRAE design guidance. The slope of the line graph was inconsistent during the six HEPA-On trials, with increasing, decreasing, and flat slopes all represented. The same observation was made for the three HEPA-Off trial runs. This lack of a conclusive trend based upon the HEPA fan's operable status appeared to indicate that any added heat originating from the HEPA fan motor was

negligible in comparison with other environmental conditions that affected the room temperature.

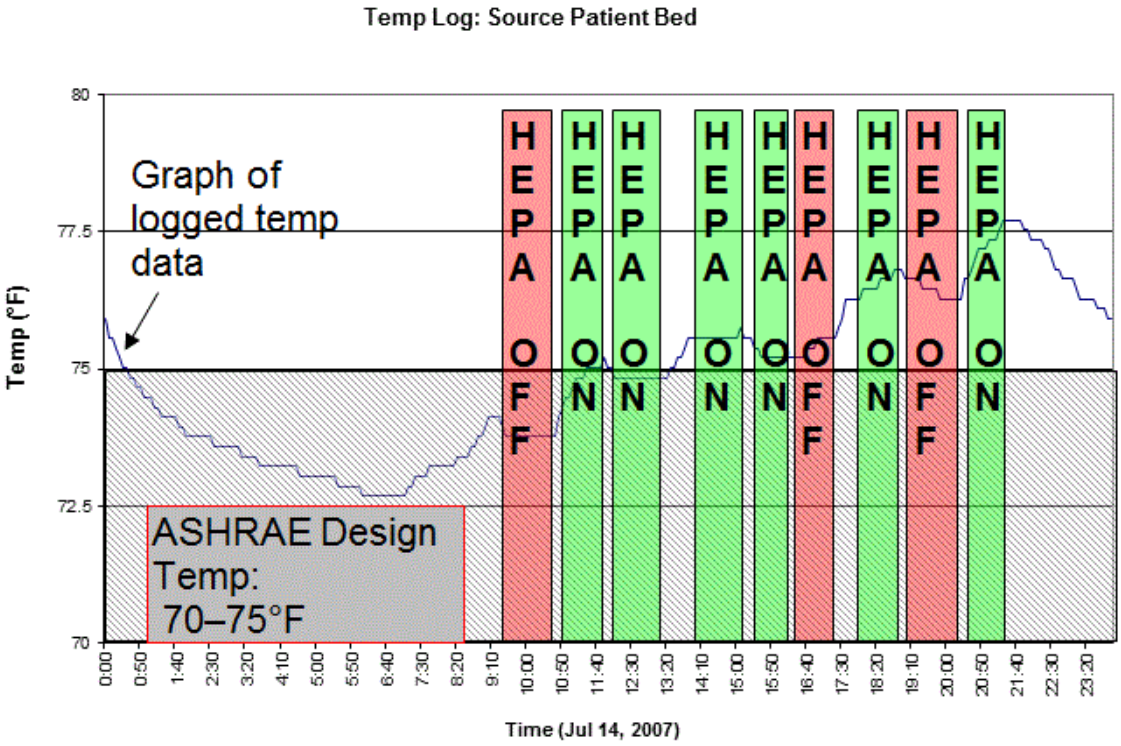


Figure 23. Graph of temperatures logged in the patient room during one day of the zone-within-zone field study at Central Kansas Medical Center, Great Bend, KS.

Ventilated Headboard, One-Patient Configuration

The ventilated headboard configuration study at CKMC was the first evaluation of such a configuration following the initial feasibility study. The patient room available for this research was a single-patient room, without an anteroom, and was not intended for airborne isolation patients. Similar to the multi-patient room, the single-patient room (Figure 24) also resembled a truncated pie-shape with an approximate floor area of 112 ft^2 and an approximate volume of 900 ft^3.

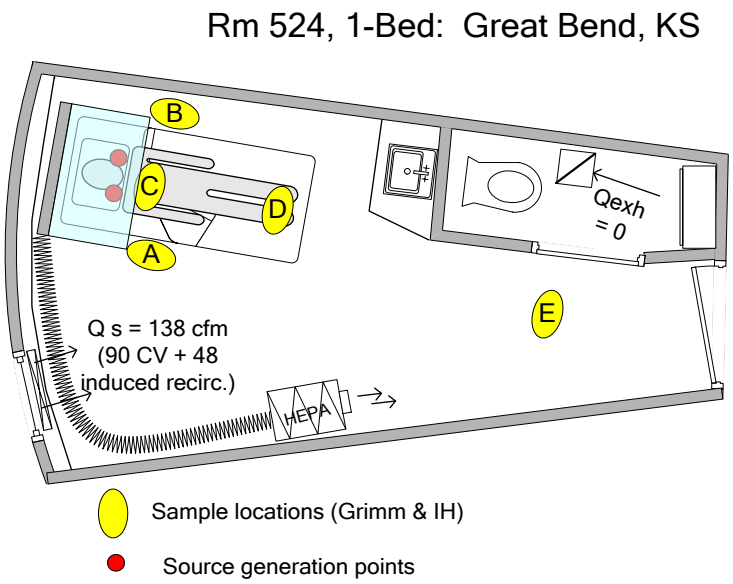


Figure 24. Schematic of ventilated headboard single-patient configuration evaluated at the Central Kansas Medical Center, in Great Bend, KS.

Configuration Setup: The ventilated headboard configuration was established according to the methodology prescribed in Chapter II. Though the single-patient room utilized a wall-mounted induction cabinet HVAC design similar to that reported for the multi-patient room, qualitative smoke tests did not indicate a need to deflect or seal either the supply louver or the kick-panel return air inlet. The HEPA filtration unit (Abatement Technologies Inc., Model PAS500, Suwanee, GA) used for this isolation configuration was of a ducted inlet design. With the rails locked into the upward (safety) position, the bed width was 42.5 in, and the width of the chosen ventilated headboard was 48 in. The CKMC ventilated headboard and hood frame, with the hood removed, are shown in Figure 25.

Figure 25. Photograph of ventilated headboard and hood frame as constructed for research at the Central Kansas Medical Center, in Great Bend, KS.

HEPA Flow Rate Determination: Given an overall room volume of 900 ft^3, a HEPA filtration flow rate of 180 cfm was required to achieve the desired 12 ACH. However, a desired minimum airflow rate through the HEPA filter unit of 240 cfm was targeted in order to provide a 30-fpm average flow velocity into the ventilated headboard's 8 ft^2 of open area. The flow rate through the HEPA filtration unit was adjustable with the variable-fan-speed controller, and a filtration flow rate of 240 cfm was achieved, resulting in a HEPA-filtered airflow of 16 ACH.

Hood Depth Determination: The Hood Depth Determination Protocol was used to establish the two hood depths (D_0 and D_0 + 8 in) to be evaluated under the two test conditions. At the CKMC, these values were 32 in and 40 in, respectively. With use of this information, two sets of inserts were made for the hood's upper side rails to facilitate quick and consistent switching between the two hood depths.

Sample Size Discussion: At this point in the field research activities, the opportunity had occurred to evaluate the data from the CKMC zone-within-zone field study for determining whether additional blocks (beyond six) would benefit the data analysis. As previously discussed, it was determined that additional blocks would be of limited benefit, and the decision was made to continue with just six blocks for each of the zone-within-zone research studies. Following the first three blocks of test runs for the CKMC ventilated headboard field study, the aerosol spectrometer data were sent back to a NIOSH statistician in Cincinnati for preliminary analysis. Since precision determinations were consistent with those seen in the zone-within-zone data, the benefit of conducting additional blocks was again seen as limited, and the decision was made for each of the ventilated headboard research studies to include six blocks of test runs, with the conditions randomly applied, in unique sequence, within the blocks.

Experimental Procedure: Five aerosol spectrometers were used for sample collection and distributed according to Figure 24. All five spectrometers were of the same model (Grimm Technologies Model 1.108) and all were set up and downloaded with Grimm's 1.177 version 3.1 software. The experimental sequence of events for the blocks followed that previously identified in the protocol, with the exception that the source aerosol was switched to 1.9-μm fluorescent beads. No other change was made to the aerosol generation protocol. Aerosol spectrometers were rotated to new, unique sampling positions after every block except block one (unintentional error) in an effort to evenly distribute potential instrument bias among the various sample positions.

The CKMC ventilated headboard field study was the first field study to use fluorescent PSL beads for subsequent filter sampling and optical counting. The sampling trains used at CKMC included 25-mm nonconductive styrene cassettes with 0.8-μm-pore MCE filters connected to IH sampling pumps with a calibrated volumetric airflow rate of 2.0 Lpm. Because of the limited availability of media, not every sample location could be filter-sampled for every block and test run. Thus, only two blocks had filter samples collected at each of the five sample positions for each of the three test conditions. Two additional blocks collected filter samples only at worker position A and room sample position E, and a fifth block included filter samples at room position E only. The sixth block did not include filter sample.

Table 9. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected at Central Kansas Medical Center in the ventilated headboard expedient isolation field study.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
HCW at right of source	A	6 **4**	0.999 **0.991**	0.997 **0.990**
HCW at left of source	B	6 **2**	0.998 **0.995**	0.998 **0.997**
Patient's chest	C	6 **2**	0.967 **0.939**	0.920 **0.888**
Foot of bed	D	6 **2**	0.996 **0.995**	0.993 **0.992**
Center of room	E	6 **5**	0.997 **0.981**	0.996 **0.989**

Performance Ratios: Table 9 shows the number of performance ratio determinations that were available at each sample position as well as the calculated GMRRs for both the aerosol spectrometer and optical counting sample methods.

Temperature Measurements: Temperature/humidity loggers were placed on the source patient bed (position C), in the center of the patient room (Position E), and on the corridor wall outside of the patient room (position not labeled). Temperatures were logged at 5-minute intervals over the three days of data collection. This particular field survey was conducted in mid-August.

For the first two days of data collection, outdoor high temperatures were in the 80s and low 90s (°F). On the third day, the high temperature increased to 98°F, and as the afternoon progressed, the high outdoor temperature appeared to moderately challenge the HVAC system's ability to keep the patient room within ASHRAE's 70–75°F design temperature. Overall, for the days upon which temperature data were collected, the HVAC system was successful in keeping environmental temperatures within the ASHRAE recommended design range (Table 10). As was the case with the zone-within-zone field study, the slightly lower temperatures observed within the corridor were believed to result from this area's nonobstructed air pathway to actively occupied (and potentially better conditioned) areas in adjacent wings of the hospital, plus the absence of a solar load from exterior walls and window surfaces.

Table 10. Summary of temperature data logged during ventilated headboard expedient isolation field study at Central Kansas Medical Center, Great Bend, KS.

Temperature in °F	**Mean**	**Min**	**Max**
Source patient bed (n = 649)	73.53	70.70	75.38
Center of patient room (n = 646)	73.43	70.88	75.92
On corridor wall (n = 649)	71.42	70.7	75.38

A line graph of temperature data logged at the patient bed position during one day of the field study is shown in Figure 26. The hatched area identifies the ASHRAE recommended design temperature range. The nine color-shaded columns represent periods of known fan/door conditions during the nine test trials (3 blocks) evaluated that day. Although the slope of the line graph was generally upward during all six of the HEPA-On fan conditions, it was also slightly upward during two of the three HEPA-Off fan conditions. This may be more closely related to the time of day and hot outdoor temperatures (above 90°F) during which the tests were conducted. In all cases, starting and ending temperatures were within 1°F of each other. Despite these trends and their possible causes, the temperature within the patient room remained within the ASHRAE recommended design criteria throughout the day of field testing.

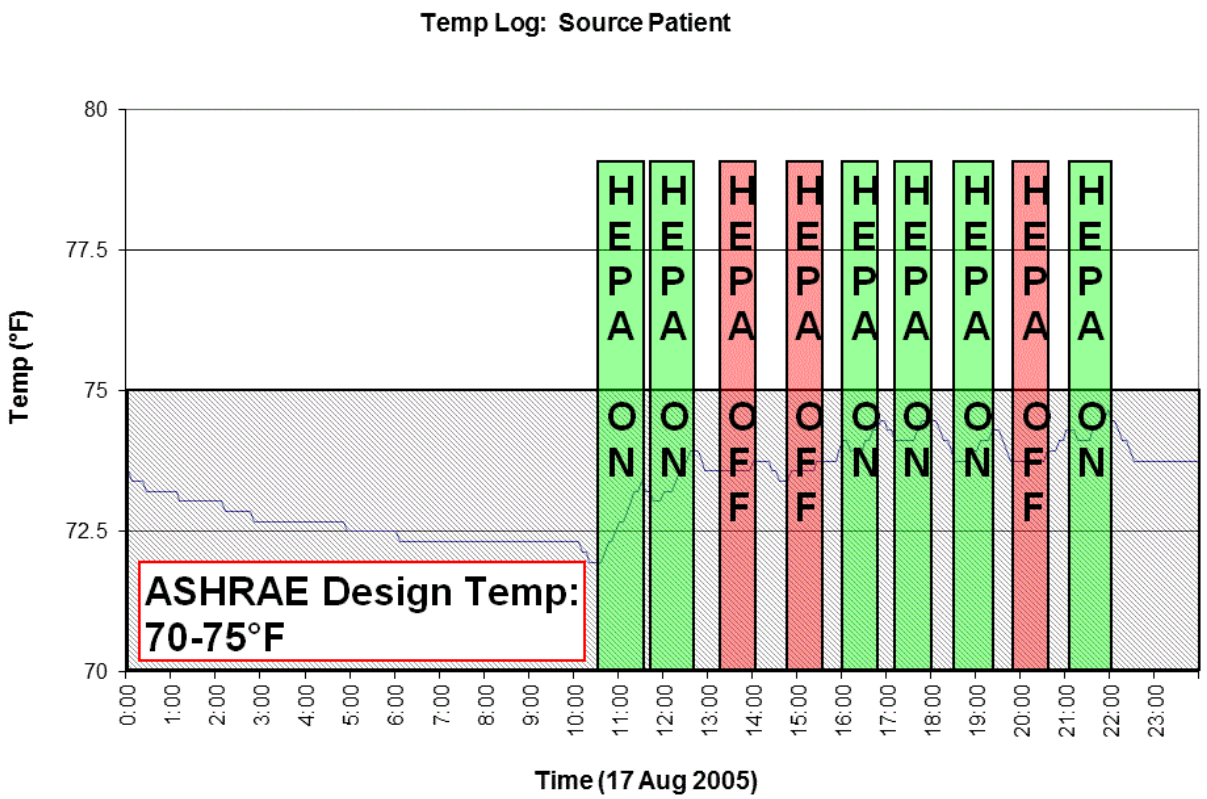


Figure 26. Graph of temperatures logged in the patient room during one day of the ventilated headboard field study at Central Kansas Medical Center, Great Bend, KS.

St Joseph Memorial Hospital, Larned, Kansas

St Joseph Memorial Hospital (SJMH) is located in Larned, Kansas (population, 4200). At the time the research was conducted, this hospital had 25 critical access beds and a 30-bed long-term-care unit. Built in 1951, the two-story facility was operated in conjunction with the CKMC in Great Bend, KS. There were no engineered AII rooms within this facility. Current practice for AII relied upon the use of a portable freestanding HEPA filtration unit until the patient could be transferred to the CKMC facility.

Zone-within-Zone, Two-Patient Configuration

The field study at SJMH was the third of the zone-within-zone expedient isolation field studies. The patient room had a floor area of approximately 210 ft^2 and an approximate volume of 1650 ft^3. The room's floor space was designed to accommodate two patient beds. For the zone-within-zone patient isolation research, the room was maintained in its two-patient configuration, as shown in Figure 27.

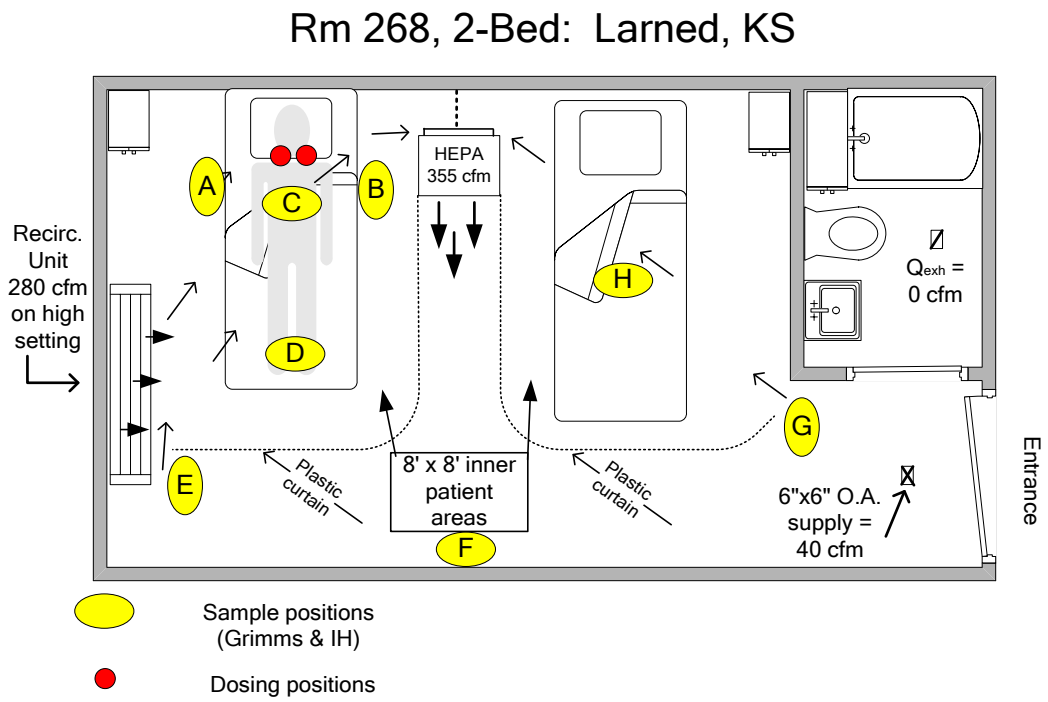


Figure 27. Schematic of zone-within-zone expedient isolation configuration at the Saint Joseph Memorial Hospital, in Larned, Kansas.

The patient room's HVAC design utilized a single 6-in by 6-in HVAC louver to supply a small amount of tempered air (primarily outdoor air plus recirculated air from the main hall) to the patient room. A 60-in by 34-in (width by height) wall-mounted recirculating fan coil unit (FCU) was the primary source of heating and cooling for the room. The SJMH field study was conducted in December, so the FCUs were in heat mode. The recirculated airflow into the FCU entered from the bottom of the unit, passed through a coarse air-conditioning filter, across the heat-exchanger coils, and out through a 5-in by 44-in supply vent.

Configuration Setup: The zone-within-zone configuration was established according to the methodology prescribed in Chapter II. The room shape and positioning of the curtain tracks required a diagonal corner-to-corner relationship between the curtain entrance gap and the HEPA inlet as shown in Figure 27. The source position was located near the HEPA inlet, consistent with the traditional bed orientation for this patient room. The freestanding HEPA filtration unit (HEPA-Care Model HC800F) was positioned equidistant between the two patient beds, such that the inlet to the HEPA unit was in line with the head position of the two patient beds. The bed height was adjusted so that the mattress height was consistent with the HEPA inlet height (approximately 28 inches from floor to top of mattress). A plastic sheeting vertical partition was built between the center of the HEPA inlet and the adjacent wall in order to separate the two inner isolation zones. The HEPA exhaust created a narrow corridor between the two patient areas. Frictional drag and induced air forces adjacent to the curtain surfaces tended to pull the curtains outward into this exhaust corridor. An adjustable-height tray table was positioned within the exhaust

corridor to resist this inward pull without obstructing the exhaust airflow (Figure 28).

Figure 28. Photograph showing HEPA exhaust corridor, with tray table in place to resist curtain pull into the corridor.

At previous field test locations, one of the evaluated test conditions had been an HVAC-sealed condition inside the inner isolation zone. This was possible because the room had other HVAC supplies to provide some tempering to the overall room. At the SJMH location, the FCU was the principle source of room air tempering. During the December field study, with its very cold weather conditions, it was quickly obvious that an HVAC-Off test condition was an unrealistic test scenario for this facility.

The FCU mounting location on the exterior wall coincided with the entrance points for that patient's inner isolation zone. This was not preferable, but it did represent a real-world implementation hurdle that could be faced by others in an emergency. Thus, this was the chosen patient position from which the source release would occur. For both of the control-on test conditions, a tunnel was created at the bottom of the FCU with plastic sheeting and packing tape. This tunnel was intended to prevent air from inside the inner isolation zone from being recirculated through the FCU during a control-on test condition. Similarly, one of the control-on test conditions (condition #3) used a similar tunnel to redirect the tempered air supply outside of the inner isolation zone during its test runs. Neither of the tunnels was used for the control-off test condition.

Figure 29. Photograph of the fan coil unit at St Joseph Memorial Hospital with expedient supply (shaded green) and exhaust (shaded red) tunnels installed.

Figure 29 shows a photograph of the FCU, the plastic tunnels, and their position relative to the inner isolation zone's entrance point. The position of the FCU relative to the plastic curtain required the curtain gap for this inner isolation zone to have an irregular shape, though the gap between the lower curtain and the FCU was consistent with the gap between the upper curtain and the exterior wall. The exterior window was a sliding window with an apparently snug fit throughout its operable perimeter; thus, no attempt was made to further restrict air leaks with tape and plastic.

A photograph showing the inlet position of the HEPA unit relative to the source patient pillow position is shown in Figure 30. A smoke test, underway at the time of the photograph, demonstrated that smoke released near the pillow area was pulled toward the HEPA inlet.

Figure 30. A photograph showing the HEPA filter unit's inlet position relative to that of the source patient's pillow position during a qualitative smoke capture test.

HEPA Flow Rate Determination: Given an overall room volume of 1650 ft^3, a minimum filtration flow rate of 330 cfm was required to achieve the desired 12 ACH. Flow rate through the HEPA unit was adjustable with a variable-fan-speed controller, and a filtration rate of 355 cfm was obtained for the control-on test conditions.

Curtain Gap Determination: The Curtain Gap Determination Protocol was conducted to establish the entrance gap widths under the two test conditions. At SJMH, the positioning of the curtain gap, the healthcare worker, the source, and the HEPA inlet required the smoke to shoot further into the isolation area before turning toward the HEPA inlet. For this reason, the entrance gap height was made smaller (7 ft) in order to increase the velocity through the remaining gap. Presence of the FCU made smoke tests difficult to conduct near the curtain gap. Multiple release points near the entrance and immediately inside the entrance were used to estimate streamline patterns. Based upon observation of the source smoke streamlines, a gap of 8 in by 7 ft between the curtain and the FCU and the curtain and the wall was selected for condition 3, where the FCU was on but partially deflected to a release point outside of the isolation curtain. Interrupting currents from the FCU prohibited the ability to conduct a meaningful smoke test under condition 2, and the decision was made to use the same curtain gap for this test condition as that used for condition 3. In addition, the interrupting discharge velocities from the FCU prohibited the ability to use the hotwire anemometer to measure incoming velocities through the curtain gap. On the basis of a mathematical (V = Q/A) examination of the HEPA flow rates and the entrance gap open area, if one assumed that virtually all the 178 cfm of makeup air entering the

inner isolation zone flowed through the curtain gap, then the velocity through the 8-in curtain gap would average about 38 fpm.

Experimental Procedure: At this point in the research effort, the decision had been finalized to conduct six blocks per field study of each configuration. Eight Grimm aerosol spectrometers (model 1.108) were used in the experimental setup. Source and sample locations were as shown in Figure 27. The three evaluated test conditions were as previously described. Unfortunately, equipment reliability issues with some of the aerosol spectrometers required a slight modification to the instrument rotation protocol. As a result, the instrument at position C remained the same throughout the experiment, and the instrument at position G remained the same for five of the six experiments. These decisions were based on the theory that results obtained at these locations were less important on account of their position (C: immediately adjacent to source) or the presence of adjacent spectrometers (position G) that would also indicate if contaminant had reached this sample position. In the end, all of the data from position C was retrievable, but only two blocks of data were retrievable from position G.

IH sampling trains were also set up at positions A, B, E, F, G, and H. These sampling trains incorporated 25-mm, 0.8-μm-pore MCE filters loaded into conductive black cowlings and connected to IH sampling pumps with a calibrated volumetric airflow rate of 1.5 Lpm. Pumps were rotated between blocks, similar to the Grimm spectrometer rotations. Sufficient filter medium was available to allow sampling at these positions for all six blocks of the field trial.

Performance Ratios: Table 11 shows the number of performance ratio determinations that were available at each sample position as well as the GMRRs for both the aerosol spectrometer and the IH filter sample data under the evaluated test conditions.

Table 11. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected at St Joseph Memorial Hospital in the zone-within-zone expedient isolation field study.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
Outside inlet 1 (source patient)	E	6 **6**	0.984 **0.937**	0.991 **0.980**
HCW (upstream)	A	6 **6**	0.241 **0.230**	0.544 **0.483**
Patient's chest	C	6	0.171	0.791
Patient's feet	D	6	0.247	0.911
HCW (downstream)	B	6 **6**	0.204 **0.300**	0.641 **0.514**
Center of outer zone	F	6 **6**	0.996 **0.948**	0.996 **0.989**
Outside inlet 2 (nonsource)	G	2 **6**	0.988 **0.912**	0.997 **0.986**
Center of bed 2 (nonsource)	H	5 **6**	0.987 **0.903**	0.991 **0.983**

Temperature Measurements: The FCUs were operated on the high fan speed for all test conditions of the SJMH field study, to represent the worst-case scenario for disrupting air currents. Unfortunately, this also caused the rooms to become very warm, so the FCUs were deactivated during non-test periods. As a result of the excessive heat output from the FCUs, it was not possible to isolate any increase in room temperature resulting from the HEPA filtration unit.

Ventilated Headboard, One-Patient Configuration

The ventilated headboard configuration study at SJMH was the second ventilated headboard evaluation following the initial feasibility study. The patient room available for this research was a two-patient room without an anteroom, a mirror image of that used for the zone-within-zone test evaluation. For consistency with the ventilated headboard field evaluations at other hospital sites (which were conducted within single-patient rooms), a temporary wall was created within this two-patient room with sheet-plastic and tape. Entrance through this wall was through a pull-back curtain, built into the temporary wall, which was taped into place to simulate an entrance door. This "door" was closed during test conditions. The resulting single-patient room configuration (Figure 31) had an approximate floor area of 145 ft^2 and an approximate room volume of 1150 ft^3.

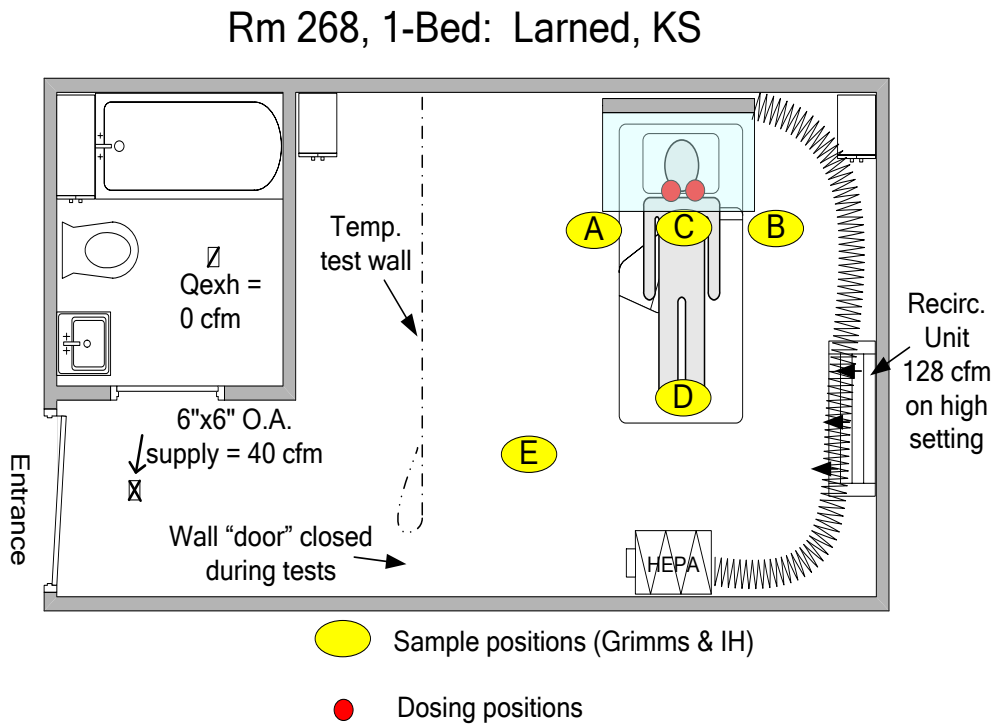


Figure 31. Schematic of ventilated headboard, single-patient room configuration evaluated at St Joseph Memorial Hospital, in Larned, KS.

Configuration Setup: The ventilated headboard configuration was established according to the methodology prescribed in Chapter II. Although the HVAC design of the two-patient room was almost identical to that described for the zone-within-zone field study, placement of the temporary wall excluded the small central HVAC supply louver from within the single-patient isolation room. Thus, the only HVAC equipment within the single-patient room was a 44-in by 29-in (width by height) wall-mounted, recirculating FCU. The FCU was placed on the "high" fan setting for all of the test run conditions. Qualitative smoke tests revealed no visibly apparent supply air interferences with the effective function of the ventilated headboard, so no deflection of the FCU was created. The HEPA filtration unit (Abatement Technologies Model PAS500) was of a ducted inlet design. The bed equipment was identical to that seen at CKMC; thus, the hood width was again chosen to be 48 inches.

HEPA Flow Rate Determination: Given a single-patient room volume of 1150 ft^3, a minimum HEPA filtration flow rate of 230 cfm was required to achieve the desired 12 ACH. This target value was increased to 240 cfm in order to provide a 30 fpm average flow velocity into the ventilated headboard. The flow rate through the HEPA filtration unit was adjustable with the HEPA unit's variable-fan-speed controller, and a filtration flow rate of 240 cfm was achieved, resulting in a HEPA filtered airflow of 12.5 ACH.

Hood Depth Determination: The Hood Depth Determination Protocol was used to establish the two hood depths (D_0 and D_0 + 8 in) to be evaluated under the two test conditions. At SJMH, these values were 28 in and 36 in, respectively. With use of

this information, two sets of inserts were made for the hood's upper side rails to facilitate quick and consistent switching between the two hood depths.

Figure 32 shows a photograph of the ventilated headboard configuration, with hood and mannequin in place and the temporary plastic "wall" in the background.

Figure 32. Photograph of ventilated headboard configuration as constructed for field research at St Joseph Memorial Hospital, in Larned, Kansas.

Experimental Procedure: As previously determined, the objective was six blocks of experimental test data, with each control scenario represented within each block. Five Grimm aerosol spectrometers (Model 1.108) were used for sample collection and distributed as shown in Figure 31. Four IH sampling trains were also set up, at positions A, B, D, and E. The sampling trains incorporated 25-mm, 0.8-μm-pore MCE filters loaded into conductive black cowling cassettes and connected to industrial hygiene sampling pumps with a calibrated volumetric airflow rate of 1.5 Lpm. Pumps were rotated between blocks, similar to the Grimm spectrometer rotations. Sufficient filter medium was available to allow sampling at these positions for all six blocks of the ventilated headboard field study.

Performance Ratios: Table 12 shows the number of performance ratio determinations that were available at each sample position, as well as the calculated GMRRs for both the aerosol spectrometer and the IH filter sample data.

Table 12. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected at St Joseph Memorial Hospital in the ventilated headboard expedient isolation field study.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
HCW at right of source	A	6 **6**	0.998 **0.991**	0.997 **0.996**
HCW at left of source	B	5 **6**	0.998 **0.990**	0.998 **0.995**
Patient's chest	C	6	0.998	0.997
Foot of bed	D	6 **6**	0.996 **0.987**	0.997 **0.989**
Center of room	E	5 **6**	0.997 **0.986**	0.998 **0.991**

Temperature Measurements: The FCU was operated on the high fan speed for all test conditions of the SJMH ventilated headboard study to represent the worst-case scenario for disrupting air currents. Unfortunately, this also caused the constructed test room to become very warm, so the FCUs were deactivated during nontest periods. Thus, it was not possible to isolate any increase in temperature that may have originated from the HEPA filtration unit.

INTEGRIS Baptist Medical Center, Oklahoma City, Oklahoma

INTEGRIS Baptist Medical Center (IBMC) was a 508-bed hospital offering comprehensive health-care programs and services. Originally constructed in 1959 as a 200-bed facility, there have been multiple additions and renovations since its original opening. This multi-story facility in Oklahoma City serves residents from this major metropolitan area (population of 506,000) as well as surrounding communities. At the time of the study, IBMC offered a full range of traditional emergency, diagnostic, therapeutic, and rehabilitative services and a wide variety of specialty rehabilitative and laboratory services. IBMC was rated as a level III trauma center and had several engineered airborne infection isolation rooms for both adult and pediatric patients. IBMC was adding additional airborne isolation capacity during the course of this field study, with a special emphasis within the emergency department.

Zone-within-Zone, Two-Patient Configuration

The zone-within-zone expedient isolation configuration study at IBMC was the fourth field study of this configuration type following the initial feasibility study. The multi-patient room had a floor area of approximately 245 ft^2 and a room volume of roughly 1965 ft^3. The room's floor space was rectangular and designed to

accommodate two patient beds, with no provisions for airborne isolation. For the zone-within-zone patient isolation research, the room was maintained in its two-patient configuration. Figure 33 is a schematic of the room layout after its conversion into a two-patient expedient isolation room.

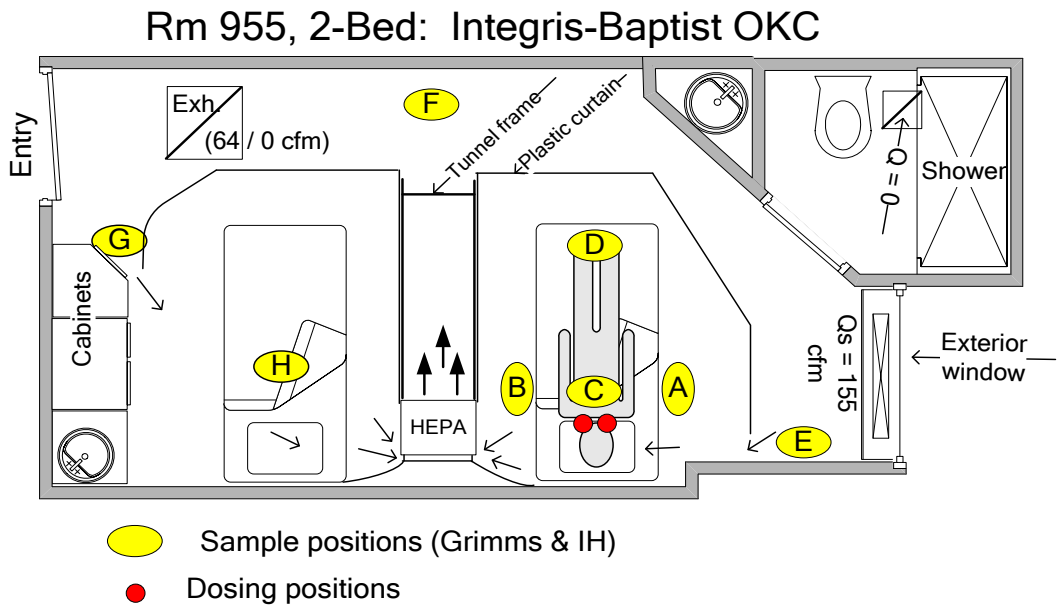


Figure 33. Schematic of zone-within-zone expedient isolation configuration at the INTEGRIS Baptist Medical Center in Oklahoma City, OK.

The 2-patient room's HVAC design included a single 5-in by 41-in linear supply diffuser positioned within a built-in cabinet and oriented upward, directly beneath a nonoperable window on the exterior wall. This supply louver was the sole dedicated source for air tempering in this patient room. Room exhaust was provided by a 2-ft by 2-ft exhaust grille located near the room's entry door.

Configuration Setup: The zone-within-zone configuration was established according to the methodology prescribed in Chapter II. The room design and curtain track positions resulted in a zone-within-zone isolation design that used a corner-to-corner diagonal airflow configuration for one bed position and a more direct, side-to-side airflow design, similar to that used at CKMC, for the second patient bed position. Since two corner-to-corner diagonal variations and only one side-to-side variation had been evaluated thus far in the field studies, the decision was made to use the side-to-side bed position as the location for the surrogate source release. Neither of the two inner isolation zones included an HVAC supply louver, and the room's existing supply louver did not appear to have an effect on the airflow within the inner isolation zone. Thus, there were no manipulations or deflections of the HVAC system to construct within the inner zones.

The freestanding HEPA filtration unit (HEPA-Care Model HC800F) was positioned equidistant between the two patient beds, such that the inlet to the HEPA unit was in line with the head-position for each bed. The beds were maintained in their

traditional orientation. The bed height was adjusted so that the mattress height was consistent with the HEPA inlet height. A plastic-sheeting vertical partition was built between the center of the HEPA inlet and the adjacent wall to separate the two inner isolation zones. The HEPA exhaust path created a narrow corridor between the two patient areas. Similar to the study at SJMH, frictional drag and induced air forces adjacent to the curtain surfaces tended to pull the isolation curtains into this exhaust corridor. At IBMC, this problem was addressed by constructing a separate tunnel, slightly smaller than the exhaust corridor, with a rigid PVC frame and tightly strung plastic sheeting along the sides of the tunnel. Figure 34 shows the end view of this tunnel, looking back toward the outlet from the HEPA filtration unit. With the tunnel in place, the tightly strung plastic sheeting, with support from the rigid tunnel frame, was fairly effective at resisting the inward pull as the discharge air passed over it, and the tunnel walls prevented these forces from being applied to the isolation zone curtain walls.

Figure 34. HEPA exhaust corridor with exhaust tunnel in place, relieving the isolation curtain from the inward pull created by frictional drag and induced air movement.

Figure 35 shows the inlet position of the HEPA unit, relative to the source patient pillow position and several of the aerosol spectrometer sample positions. An inlet baffle (shaded in transparent yellow in the picture) was created with plastic sheeting and angled between the HEPA inlet and the wall, which helped direct the airflow streamlines toward the HEPA inlet with reduced turbulence.

Figure 35. The HEPA filter unit's inlet position (and turbulence-reducing baffle) relative to the source patient's pillow position and aerosol spectrometer sampling positions A, C, and B.

HEPA Flow Rate Determination: Given a room volume of 1965 ft^3, a HEPA filtration minimum flow rate of 395 cfm was required to achieve the desired 12 ACH. The fan speed and corresponding flow rate through the HEPA filter could be adjusted with the unit's variable-fan-speed controller, and a filtration rate of 400 cfm was achieved for control-on test condition 2. Since there were no HVAC supply louvers within the inner isolation zone to manipulate for a test condition 3, an alternate test condition 3 was identified to evaluate the effectiveness of the zone-within-zone configuration when the HEPA filtration unit was operated at its highest fan speed. When the variable-fan-speed controller was at its highest setting, the flow hood measurement on the exhaust side of the HEPA unit was 470 cfm. This was equivalent to a filtration rate of 14.4 ACH.

Curtain Gap Determination: For the source patient isolation zone, the entrance gap was directly across the pillow from the HEPA inlet. However, the flow rates through the inner isolation zones were sufficiently similar that a difference in gap width requirements between the two control-on test conditions was not discernible. Only condition 2 (12-room ACH HEPA setting with no HVAC source within inner isolation zone) was consistent with the other field study locations. On the basis of observation of the source smoke streamlines, while using the Curtain Gap

Determination Protocol, a gap of 12 in by 7 ft was selected for entrance into the source-patient's inner isolation zone.

Centerline velocity measurements for the Condition 2 test condition resulted in a mean inward velocity of only 16 fpm (range, 1–46 fpm; n = 7). Unfortunately, 6 of 7 velocity measurements were less than the VelociCalc's reliable limit of 30 fpm, so this result was in question. Based upon a mathematical (V = Q/A) examination of the HEPA flow rates and the entrance gap open area, the average expected velocity through the gap would be 28 fpm. Similarly, at the slightly higher flow for condition 3, the average expected velocity through the gap would be about 33 fpm.

One change to no-control test condition 1 unique to IBMC was driven by concerns that the HVAC supply, located immediately outside of the entrance gap, would trap source aerosol within the inner zone and retard its ability to distribute throughout the room. Under normal conditions with cloth curtains, this would not occur because of the open area above and below the curtain. To address this unique situation, the plastic curtain was retracted to a gap of approximately 3 feet, and the bottoms of the curtain were lifted and taped into place to provide a horizontal gap of about 1½ feet between the floor and the bottom of the retractable portions of the isolation curtains.

Experimental Procedure: Six blocks of experiments were planned for this expedient isolation field study. The sequence of operations for the blocks followed that previously identified in the protocol, and individual Grimm instruments were rotated to a new, unique position assignment before each block in order to reduce potential instrument-associated bias upon a single sample location. Eight Grimm aerosol spectrometers (Model 1.108) were used in the experimental setup. Source and sample distribution were as shown in Figure 33.

IH sampling trains were also set up at positions A, B, D, E, F, G, and H. These sampling trains incorporated 25-mm, 0.8-μm -pore MCE filters loaded into conductive black cowling cassettes and connected to IH sampling pumps with a calibrated flow rate of 1.5 Lpm. Pumps were rotated between blocks, similar to the Grimm spectrometer rotations. Sufficient media were available to allow sampling at these positions for all six blocks of the field trial.

Performance Ratios: Table 13 shows the number of performance ratio determinations that were available at each sample position as well as the GMRRs for both the aerosol spectrometer and the IH filter sample data under the evaluated test conditions.

Table 13. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected at the INTEGRIS Baptist Medical Center in the zone-within-zone expedient isolation field study.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
Outside inlet 1 (source bed)	E	6 **6**	0.998 **0.999**	0.998 **1.000**
HCW (upstream)	A	6 **6**	0.998 **0.994**	0.998 **0.999**
Patient's chest	C	6	0.998	0.999
Patient's feet	D	6 **6**	0.999 **0.998**	0.998 **0.999**
HCW (downstream)	B	6 **6**	0.996 **0.996**	0.999 **0.999**
Center of outer zone	F	6 **6**	0.995 **0.999**	0.996 **0.999**
Outside inlet 2 (nonsource)	G	6 **6**	0.998 **0.999**	0.997 **0.999**
Center of Bed 2 (non-source)	H	6 **6**	0.998 **0.999**	0.996 **0.999**

Temperature Measurements: Only two temperature/humidity loggers were available for use at the IBMC field study site. These were placed on the source patient bed (position C) and on the corridor wall, outside of the patient room (position not labeled). Temperatures were logged at 5-minute intervals over the four days of data collection. The outdoor temperatures and internal heat loads did not appear to challenge the HVAC system's ability to keep the patient room within ASHRAE's 70–75°F design temperature range, as reflected in the temperature data summary shown in Table 14.

Table 14. Summary of temperature data logged during zone-within-zone expedient isolation field study at INTEGRIS Baptist Medical Center, Oklahoma City, OK.

Location	Temperature in °F		
	Mean	Min	Max
Source patient bed (n = 868)	70.49	68.54	74.66
On corridor wall (n = 1061)	70.95	69.80	73.22

A line graph of temperature data logged at the source bed position during one day of the field study is shown in Figure 36. The hatched area identifies the ASHRAE-recommended design temperature range. The nine color-shaded columns represent periods of known fan/door conditions that correspond to the 3 blocks evaluated that day. All of the recorded temperatures were below the 75°F upper limit of the ASHRAE design guidance. The slope of the line graph was downward, indicating a decrease in temperature over the testing period, for five of six HEPA-On test trials and all three of the HEPA-Off trials. The one HEPA-On trial with an increasing slope was very moderate (approximately 0.5 °F/1 hour) in magnitude. The lack of increasing slopes associated with the HEPA fan's operable status appeared to indicate that any added heat originating from the HEPA fan motor was negligible compared to other environmental conditions that affected the room temperature.

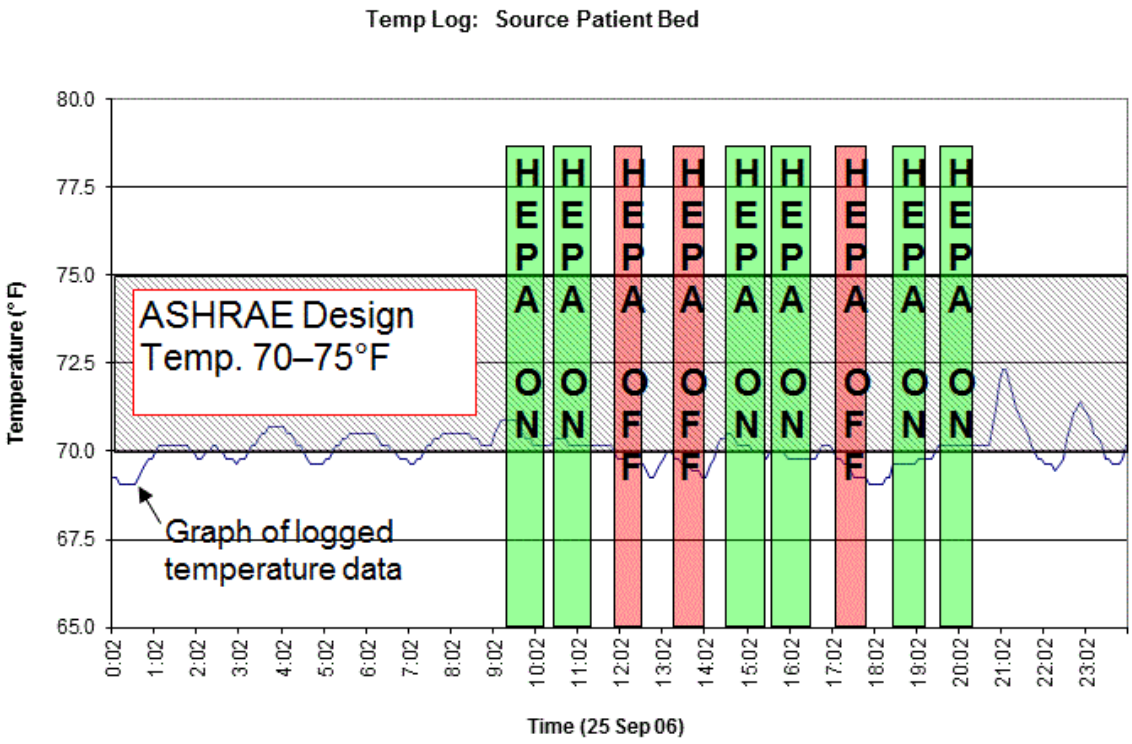


Figure 36. Graph of temperatures logged in the patient room during one day of the zone-within-zone field study at INTEGRIS Baptist Medical Center, Oklahoma City, OK.

Ventilated Headboard, One-Patient Configuration

The configuration study at IBMC was the fourth ventilated headboard evaluation following the initial feasibility study. The room available for this research was a single-patient room not designed for airborne isolation capabilities. However, the room did have an adjacent sitting/waiting area for family and other visitors. During the IBMC ventilated headboard evaluations, the partition between the patient room and the waiting area remained closed and moderately sealed with tape and plastic to reduce potential aerosol migration between areas. Thus, the waiting area was not considered part of the patient room for the purposes of this study. The patient room floor area was approximately 190 ft^2. With combined 9-ft and 8-ft ceiling heights, the overall room volume was approximately 1680 ft^3 (Figure 37).

Configuration Setup: The ventilated headboard configuration was established according to the methodology prescribed in Chapter II. The room's HVAC design utilized a 2-ft by 2-ft exhaust grille located near the room's entry door and two 5-in by 29-in supply louvers to supply tempered air from a central HVAC unit. These supply louvers were located within the top of a small built-in cabinet on the exterior wall and more than seven feet away from the patient bed position. Qualitative smoke tests revealed no visibly apparent supply air interferences with the effective function of the ventilated headboard, so no deflection of the supply louvers was

made. The exhaust louver was sealed, depending upon test condition, as previously described in the protocol.

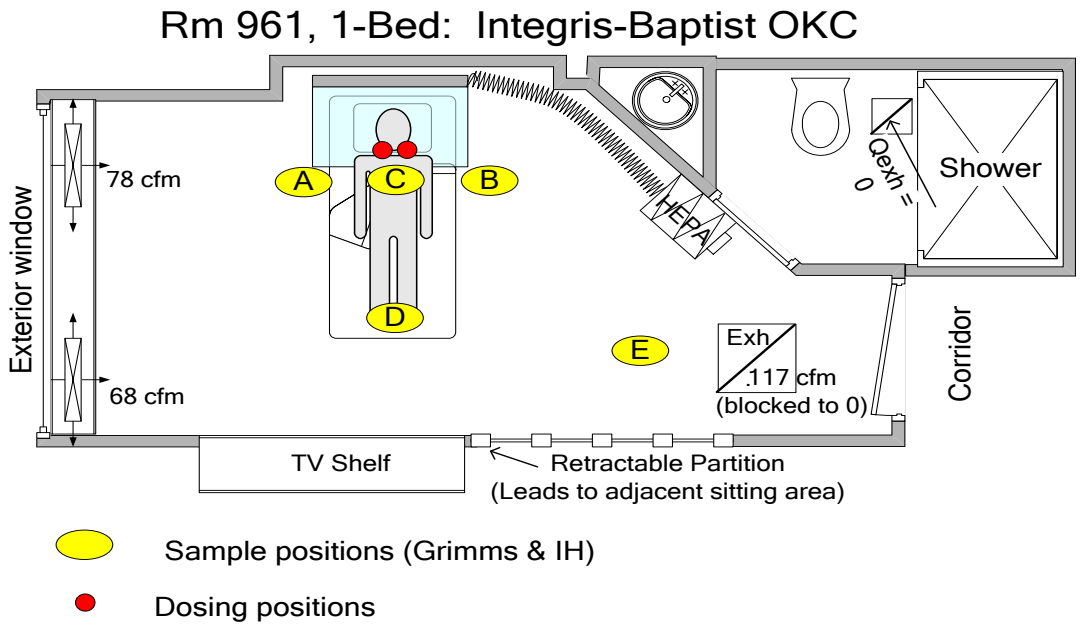


Figure 37. Schematic of ventilated headboard single-patient configuration evaluated at the INTEGRIS Baptist Medical Center in Oklahoma City, OK.

The HEPA filtration unit was an Abatement Technologies Model PAS500 with a ducted inlet design. The bed measured 42 in wide with the rails in the upward safety position; however, they required an additional 2 in of width (1 in per side) in order to move the rails between the raised and lowered positions, resulting in a total width requirement of 44 in. The same ventilated headboard as that used at the VA Medical Center was also used at IBMC. This headboard measured 4 ft wide by 2 ft high. Figure 38 shows a photograph of the ventilated headboard configuration with hood, mannequin, and sampling equipment in place.

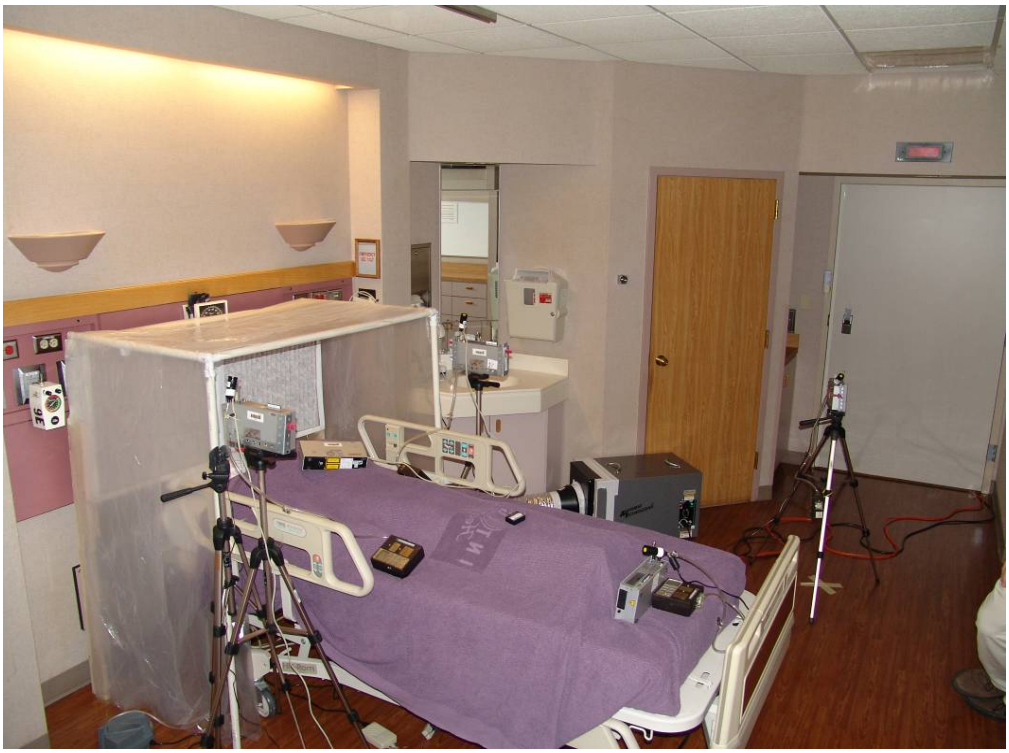


Figure 38. The ventilated headboard configuration as constructed for field research at the INTEGRIS Baptist Medical Center, in Oklahoma City, OK.

HEPA Flow Rate Determination: Given a room volume of 1680 ft^3, a HEPA filtration flow rate of 335 cfm was required to achieve the desired 12 ACH. The flow rate through the HEPA filtration unit could be adjusted with the HEPA unit's variable-fan-speed controller; however, at its highest fan-speed setting, the maximum flow rate through the hood was only 280 cfm. Thus, despite the desired 12 ACH designated by the research protocol, the IBMC ventilated headboard configuration utilized a HEPA filtration air-cleaning rate of only 10 ACH for the control-on test conditions. Although an unintended deviation from the protocol, the "effective ventilation rate" of 10 ACH still exceeds the minimum 6 ACH recommended ventilation rate for existing facilities in the CDC's *2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings* [Siegel et al. 2007].

Hood Depth Determination: The Hood Depth Determination Protocol was used to establish the two hood depths (D_0 and D_0 + 8 in) to be evaluated under the two test conditions. At IBMC, these values were 26 in and 34 in, respectively. Two sets of inserts were made for the hood's upper side rails to facilitate quick and consistent switching between the two hood depths.

Experimental Procedure: The predetermined objective was six blocks of experimental data, with each condition represented within each block. Five aerosol spectrometers (Grimm Model 1.108) were distributed according to Figure 37. Individual spectrometers were rotated to a new position before each block. Four IH sampling trains were placed at positions A, B, D, and E. These sampling trains incorporated 25-mm, 0.8-μm-pore MCE filters loaded into conductive black cowling

cassettes and connected to IH sampling pumps with a calibrated flow of 1.5 Lpm. Pumps were rotated between blocks, similar to the spectrometer rotations. Sufficient filter medium was available to allow sampling at these positions for all six blocks of the ventilated headboard field study.

Performance Ratios: Table 15 shows the number of performance ratio determinations that were available at each sample position, as well as the GMRRs for both the aerosol spectrometer and the IH filter sample data under the evaluated test conditions.

Table 15. Geometric mean reduction ratios (GMRRs) for Grimm aerosol spectrometer data (black values) and filter sampling/optical counting data (red values) collected at INTEGRIS Baptist Medical Center in the ventilated headboard expedient isolation field study.

Position Description	Location Label	n	GMRR Test Condition 2	GMRR Test Condition 3
HCW at right of source	A	6	0.998	0.998
		6	**1.000**	**1.000**
HCW at left of source	B	6	0.999	0.998
		6	**1.000**	**1.000**
Patient's chest	C	6	1.00	1.00
Foot of bed	D	6	0.998	0.998
		6	**1.000**	**1.000**
Center of room	E	6	0.999	0.997
		6	**1.000**	**1.000**

Temperature Measurements: Three temperature/humidity loggers were initially used during the IBMC ventilated headboard field study. These were placed on the source patient bed (position C), on the corridor wall, outside of the patient room (position not labeled), and in the adjacent seating area (position not labeled); however, the temperature data from the adjacent sitting area were not retrievable. Temperatures were logged at 5-minute intervals over the three days of data collection. Table 16 is a summary of the logged temperature data collected during the ventilated headboard field study. The logged temperatures from the corridor location were all within or below ASHRAE's 70–75°F design temperature guidance. The temperatures logged at the patient position show maximum temperatures above the ASHRAE recommended range. A closer examination of the data files revealed that just 6 out of 613 data points exceeded the 75°F upper limit, and all of these were consecutive measurements observed after conclusion of the first day of testing. On the basis of the timing of these six observations, they were believed to reflect the heated exhaust air originating from a laptop computer during equipment

download activities. If these six data points are ignored, then none of the remaining 607 temperature measurements exceeded the ASHRAE 70–75°F design guidance.

Table 16. Summary of temperature data logged during the ventilated headboard expedient isolation field study at INTEGRIS Baptist Medical Center, Oklahoma City, OK.

Location	Temperature in °F		
	Mean	Min	Max
Source patient bed (n = 613)	70.45	67.28	80.78
On corridor wall (n = 613)	71.16	69.98	72.68

A line graph of temperature data logged at the source bed position during one day of the field study is shown in Figure 39. The hatched area identifies the ASHRAE-recommended design temperature range. The six color-shaded columns represent periods of known fan/door conditions that correspond to the two blocks evaluated that day. All of the recorded temperatures were below the 75°F upper limit of the ASHRAE design guidance. With the exception of the first HEPA-On test run, the slope of the line graph was relatively flat or downward, indicating no increase in observed temperature over the testing period for three of four HEPA-On test trials and both of that day's HEPA-Off trials. The one HEPA-On trial with an increasing slope was relatively small (approximately 0.5°F/1 hour) in magnitude. The lack of increasing slopes associated with the HEPA fan's operable status appears to indicate that any added heat originating from the HEPA fan motor was negligible, compared to other environmental conditions that affected the room temperature.

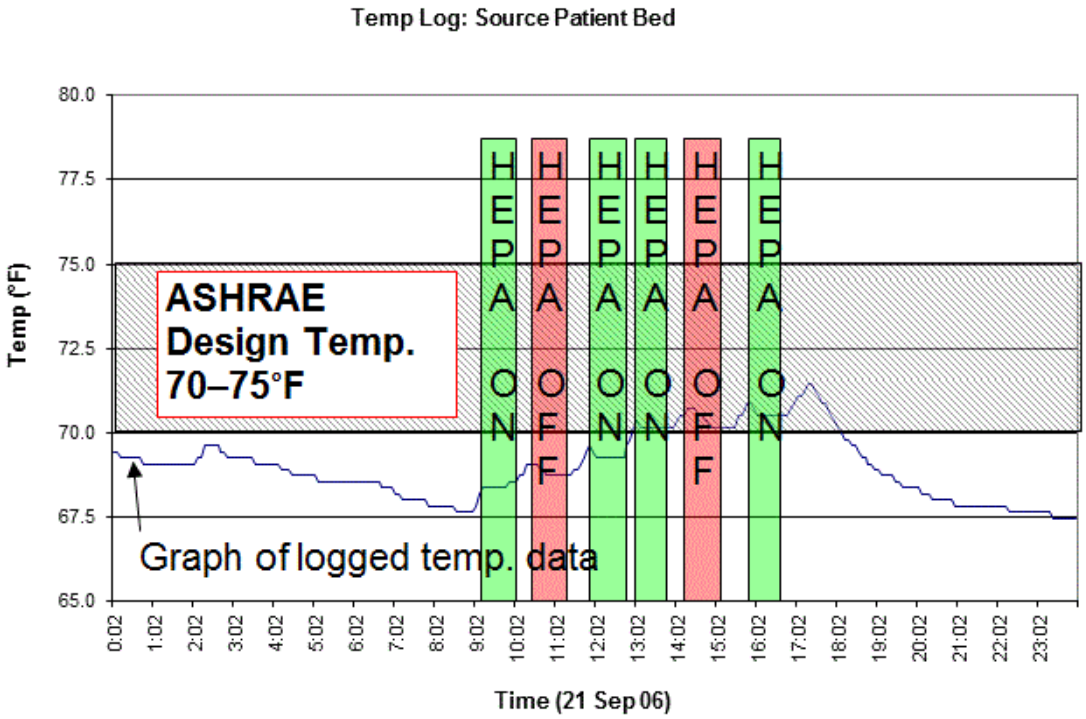


Figure 39. Graph of temperatures logged in the patient room during one day of the ventilated headboard field study at INTEGRIS Baptist Medical Center, Oklahoma City, OK.

Summary of Physical Field Conditions

Tables 17 (zone-within-zone) and 18 (ventilated headboard) summarize the field conditions encountered and established for the expedient isolation field studies conducted at each of the four hospital locations.

Table 17. Summary of field conditions associated with the four zone-within-zone field studies conducted under this research.

Condition	Zone-Within-Zone Field Studies			
	VAMC	**CKMC**	**SJMH**	**IBMC**
Hospital Type	Urban	Rural	Rural	Urban
Room area (ft^2)	320	345	210	245
Room volume (ft^3)	2570	2760	1650	1965
HVAC design(1)	Central	Combo	Recirc	Central
HEPA model(2)	NuAire (FS)	AT HEPA-Care HC800F (FS)	AT HEPA-Care HC800F (FS)	AT HEPA-Care HC800F (FS)
HEPA flow (cfm)	550	550	355	400/470(4)
Flow orientation	Diagonal	Side-to-side	Diagonal	Side-to-side
Condition 2(3) entrance gap width (in.) /velocity (fpm)	10/30	10/37*	8/38*	12/16 (28*)(5)
Condition 3(3) entrance gap width (in.) /velocity (fpm)	12/38	12/34*	8/38*	12/33*

(1) Central = Central HVAC; Recirc = in-room recirculation unit; Combo = Combination of central HVAC supply + room recirculation.
(2) FS = freestanding; D = ducted inlet.
(3) Asterisk indicates a calculated velocity value.
(4) Alternate Condition 3 at IBMC led to two HEPA flow rates of 470 cfm = 14.4 ACH.
(5) Six of 7 measured velocities below reliable limit; second value = calculated velocity.

Table 18. Summary of field conditions associated with the four ventilated-headboard field studies conducted under this research.

Condition	Ventilated Headboard Field Studies			
	VAMC	CKMC	SJMH	IBMC
Room area (ft^2)	121	112	145	190
Room volume (ft^3)	970	900	1150	1680
HVAC design(1)	Central	Combo	Recirc	Central
HEPA model(2)	AT PAS600(D)	AT PAS500(D)	AT PAS500(D)	AT PAS500(D)
HEPA flow (cfm)	240	240	240	280(3)
Filtration ACH (cfm)	14.8	16	12.5	10
Condition 2 hood depth (in.)	28	32	28	26
Condition 3 hood depth (in.)	36	40	36	34

(1) Central = Central HVAC; Recirc = in-room recirculation unit; Combo = Combination of central HVAC supply + room recirculation.
(2) (D) = ducted inlet; AT = Abatement Technologies.
(3) Maximum flow achievable with this configuration and this HEPA filter unit.

Chapter IV

Analysis and Discussion

Aerosol Spectrometer Data

Using the aerosol spectrometer particle count data, 26 particle counts were identified as the data to be analyzed for each block/test run/measurement position. These particle counts were entered into the SAS statistical package, which was programmed to conduct the previously described background correction, baseline shift, log transformation, and arithmetic mean determinations, resulting in a single representative data point on a log-transformed scale for each set of block/run/position observations. These values were then evaluated with SAS Proc Mixed to provide a lower limit for the geometric mean reduction ratio at $\alpha = 0.10$. The decision to use SAS Proc Mixed was based upon its improved ability to account for variance contributions that result from multiple random effects and to model data with nonconstant variances across groups.

One of the considerations for the statistical analysis was whether to have the reduction limits calculated with use of individually corrected or simultaneously corrected lower limits. Simultaneously (a.k.a. Bonferroni) corrected results must share the designated level of confidence (α-value) among each of the sampling positions (leading to wider confidence intervals), whereas the individually corrected results were each evaluated at the designated α-value in determining their lower limits. The verdict on whether simultaneous correction was applicable for this research scenario was somewhat subject to individual opinion. The rationale behind simultaneous correction was that the results for a designated sample position were not independent observations but may have been impacted by the control results at other sample positions in the room. Intuitively, this made sense for some sample positions; however, at other locations (e.g., at patient's chest vs. in center of room), such interdependence would be expected to play less of a role in actual worker exposures. For purposes of this research, sample positions that healthcare providers would be expected to avoid, where exposure reductions were not expected due to their obvious location within the contaminant exhaust path, were eliminated from consideration in the SAS model. These included, for the zone-within-zone configuration, the center chest positions, due to their proximity to the actual source, and the downstream healthcare worker positions, due to their known proximity to the downstream path of contaminant-carrying airflows. Since these positions also tended to have greater variability in their observations, the decision to eliminate them from the model resulted in the additional benefit of reducing the overall variability within the model. The output reports from the SAS analysis are included in Appendix B. In these reports, both the individually corrected and the simultaneously corrected results for the lower reduction limits are reported from the model. The geometric mean reduction ratio estimates for the Zone-Within-Zone field studies, along with their simultaneously corrected lower limits (shown in parentheses) as predicted by the SAS model, are summarized in Table 19.

Table 19. Summary of geometric mean reduction ratios (GMRRs) and lower limits (in parentheses) for the zone-within-zone (2-bed) expedient isolation field studies at the four research sites; aerosol spectrometer data simultaneously corrected for α = 0.10 (see Notes).

Sample Position	VAMC		CKMC		SJMH		IBMC	
	2:1	3:1	2:1	3:1	2:1	3:1	2:1	3.1
HCW, upstream	**0.134** (**-4.10**)	**0.163** (**-5.65**)	0.998 (0.993)	0.993 (0.971)	**0.241** (**-0.536**)	**0.544** (**0.076**)	0.998 (0.986)	0.998 (0.989)
HCW, downstream	**-0.767** (na)	**-0.800** (na)	0.928 (na)	0.993 (na)	**0.204** (na)	**0.641** (na)	0.996 (na)	0.999 (na)
Patient chest	na (na)		**0.761** (na)	1.00 (na)	**0.171** (na)	**0.791** (na)	0.998 (na)	0.999 (na)
Patient feet	na (na)		na (na)		**0.247** (**-0.525**)	0.911 (**0.821**)	0.999 (0.994)	0.998 (0.991)
Outside gap 1	0.998 (0.991)	0.999 (0.989)	0.998 (0.994)	0.993 (0.983)	0.984 (0.968)	0.991 (0.982)	0.998 (0.987)	0.998 (0.991)
Center room	0.999 (0.994)	0.999 (0.991)	0.999 (0.996)	0.998 (0.996)	0.996 (0.992)	0.996 (0.992)	0.995 (0.970)	0.996 (0.979)
Outside gap 2	0.993 (0.958)	0.997 (0.979)	0.999 (0.996)	0.999 (0.998)	0.988 (0.965)	0.997 (0.989)	0.998 (0.987)	0.997 (0.981)
Bed 2	0.987 (0.942)	0.997 (0.989)	0.999 (0.996)	0.996 (0.991)	0.987 (0.971)	0.991 (0.982)	0.998 (0.990)	0.996 (0.979)

Notes:
HCW = Healthcare worker
VAMC = VA Medical Center
CKMC = Central Kansas Medical Center
SJMH = St. Joseph Memorial Hospital
IBMC = INTEGRIS Baptist Medical Center
"2:1" indicates GMRRs for test condition 2 relative to test condition 1 (no control);
"3:1" similarly indicates GMRRs for test condition 3
double-strike horizontal line at mid-table separates samples collected within the source isolation zone from those collected outside of this zone
yellow highlight with bold font indicates GMRRs below 0.90.

In Table 19, yellow highlights show the reported reduction ratios that were less than 90 percent. This 90 percent threshold is consistent with an assigned protection factor of 10, which is the level of protection that half-mask respirators (including N95) are expected to provide in the workplace if used in accordance with a respiratory protection program that follows the requirements prescribed in OSHA

1910.134 *Respiratory Protection* [OSHA 1998]. It should be noted that a component of the OSHA-prescribed respiratory protection program requires users to be enrolled in a respiratory protection program that includes annual fit-testing. However, fit-testing healthcare workers for N95 respirators has been a controversial subject and compliance is not always universal. In 2005 and 2006 the annual congressional appropriations bills prohibited OSHA from enforcing annual fit-testing requirements for protection from tuberculosis. This prohibition extended through FY2007 and into FY2008 as a result of omnibus continuing resolutions [Perlin 2005; Shalhoub 2007]. The enforcement restriction was finally lifted with the presidential signing of the FY2008 Omnibus spending bill in late 2007 [OSHA 2008]. If allowed to return, such non-enforcement policies could become critical in the event of an airborne infectious epidemic, if healthcare workers have not been fit-tested and there is insufficient time to initiate such testing. NIOSH researchers have demonstrated that in the absence of proper fit-testing, the protection factor afforded by N95 respirators can drop below 50 percent [Coffey et al. 1999, 2004].

Zone-Within-Zone Configuration

As discussed in Chapter III, the zone-within-zone expedient isolation configurations varied moderately by field site. Studies conducted at VAMC and SJMC (gray-shaded columns in Table 19) utilized a corner-to-corner-oriented airflow, but the studies at CKMC and IBMC utilized a side-to-side airflow over the mannequin's upper torso. The double-struck horizontal line in Table 19 demarks the separation between sample positions located within the source isolation zone and outside the zone. Across the four survey sites, all results (GMRR estimates and their corresponding lower limits) reported for sample positions outside the source control zone reflected levels of control exceeding the 90 percent threshold. All 32 of the outer-zone GMRR point estimates exceeded 98 percent, and 28 of those 32 were greater than 99 percent. Thus, reduction ratio performance outside the source isolation zone was consistently effective, regardless of the inner isolation zone's airflow configuration.

For samples collected within the source isolation zone, results observed at the healthcare worker sample positions for the side-to-side airflow configurations tested at CKMC and IBMC were consistently above the 90 percent criterion, with 7 of 8 GMRR estimates exceeding 99 percent reductions. The 0.761 reduction ratio highlighted in yellow from the CKMC field study was from data collected at the center of the patient's chest, within a couple of inches from the source discharge, and does not represent a valid sampling location for worker exposures. Results for the corner-to-corner airflow configurations tested at both VAMC and SJMH failed to achieve the criterion (of 90 percent contaminant concentration reduction) relevant to the noncontrolled test condition. However, these sample locations still benefited from the increased ventilation rates that resulted from concentrating the specified 12 ACH (based on room volume) to pull from within the smaller volume of the inner isolation zones. For comparison purposes, the effective ACH ventilation rate at these sample positions can be calculated by analysis of the concentration decay following nebulizer shutdown. For example, Figure 40 shows the concentration decay curve generated from the HCW Upstream particle count data at VAMC under a Condition 2 test run (GMRR = 0.134). Knowledge of the graphic representations of the ventilation purging equation discussed earlier can be used to determine

ventilation rates for a given volume. If one considered the moment of nebulizer shut off as time T_o and plotted the natural log transformations of the observed particle counts over one-minute intervals throughout the 10-minute decay, then linear regression could be used to determine a straight trend line to represent the decay [Grieve 1989]. The magnitude of the slope of this trend line was the effective ventilation rate in air changes over a time interval *T*, which in this case was one minute. Multiplying this result (0.4343 on Figure 40) by 60 minutes/hour yielded 26 ACH, which was more than twice the decay rate expected from an engineered AII room's 12 ACH ventilation rate.

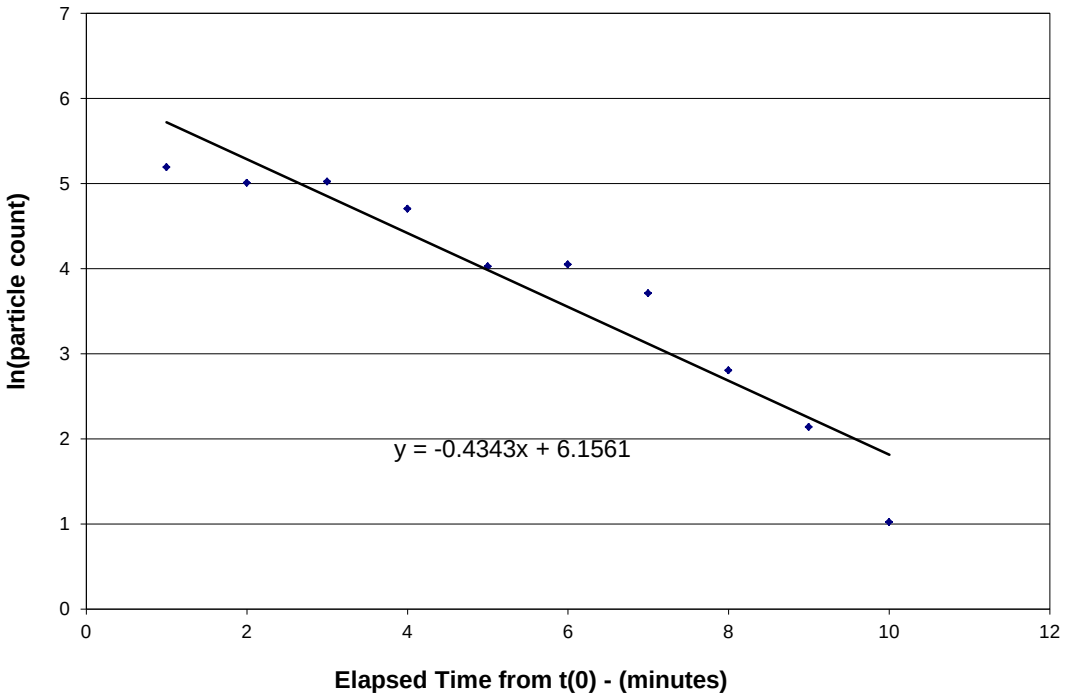


Figure 40. Graph of particle count decay observed at the upstream healthcare worker position during a Condition 2 trial run of the zone-within-zone expedient isolation field study, VA Medical Center, Oklahoma City, OK.

Another way to provide meaningful interpretation of the GMRR data in Table 19 would be to present them as Expedient Isolation Protection Factors (EIPF). If defined as a surrogate measure of the workplace protection provided by an expedient airborne isolation intervention, the EIPF would be analogous to Simulated Workplace Protection

Factor (SWPF), which NIOSH defines as "a surrogate measure of the workplace protection provided by a respirator" [NIOSH 2004]. The EIPF can be calculated by:

$$EIPF = \frac{1}{1 - GMRR}$$

According to this formula, EIPFs calculated from the reduction ratio estimates for sample positions outside of the source isolation zone range from 63 to 1000, with lower limits ranging from 17 to 500. Inside the source isolation zones, calculated EIPFs for the corner-to-corner airflow configurations ranged from negligible to nonprotective, largely due to contaminants being concentrated within a smaller dilution volume (relative to the overall patient room) and/or sample locations within the airborne contaminant flow path as it was pulled toward the HEPA inlet (e.g., downstream HCW position at VAMC). Calculated EIPF estimates for upstream worker positions within the side-to-side airflow configuration ranged from 143 to 1000, with lower limits ranging from 34 to 143.

Engineered AII rooms rely upon contaminant removal and dilution from general ventilation to provide airborne concentration reductions. Guidelines such as the CDC's 2005 *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings* provide dilution tables similar to Table 2 of this document and advise healthcare workers or other visitors to delay entering a room where a tuberculosis patient may have been coughing, until "sufficient time" has elapsed for adequate dilution/removal of the *M. tuberculosis*–contaminated air. One benefit that direct source control provides over dilution is the significant reduction of time required to achieve a stated reduction in cough-generated aerosol. Concentration reductions provided by expedient isolation configurations that use source capture as a control mechanism represent real-time reductions of a continuous contaminant source that existed throughout the duration of the test scenario. Real-time concentration reductions can be represented in terms of a Protective Time Equivalent (PTE), which can be defined as the amount of elapsed time required for the same concentration reduction to occur in an engineered AII room designed to provide 12 ACH of dilution ventilation. The PTE can be calculated with a slightly modified version of the dilution equation, previously used to generate Table 2:

$$PTE = -\ln\left[\frac{(1-GMRR)}{(12ACH)}\right]\times 60\times K$$

where:

PTE = Protective Time Equivalent (minutes)

GMRR = geometric mean reduction ratio

12 ACH = specified AII room ventilation rate

K = Ventilation mixing factor (assumed good mixing, K = 3)

The PTE provides another metric by which to evaluate the benefits offered by an expedient isolation configuration and is a metric that may hold greater meaning to hospital administrators and others involved in workforce/bed/patient management. Focusing primarily upon locations outside of the source isolation zone as well as the CKMC and IBMC healthcare worker sample positions where concentration reductions

(relative to the no-control test condition) occurred, we can also express the benefits of concentration reductions at these locations in terms of the PTE.

Application of the PTE within the healthcare industry is proposed to reduce the amount of waiting time considered necessary for safe entry into areas (patient rooms, ambulances, operating rooms, special treatment rooms, autopsy rooms) potentially contaminated by individuals with known or suspected airborne infectious disease. Several CDC guidance documents provide recommendations to "…allow adequate time for ACH to clean 99 percent of airborne particles from the air" and go on to provide a Table of ACH and time required for various airborne-contaminant removal efficiencies [CDC 1994, 2004, 2007]. These tables are generally similar to Table 2 in this document. Consider a traditional patient room which had been augmented (for surge purposes) through portable HEPA filtration to achieve an equivalent ventilation rate of 12 ACH and good air mixing (K = 3); these tables recommend a 69-minute wait before room re-entry or occupancy by another patient. However, if the HEPA filtration were incorporated into an expedient airborne isolation configuration with a known PTE such as those discussed in this document, the PTE could be subtracted from the designated wait time to result in a total to near-total reduction in time required for room entry. Depending upon the room type (for example, emergency department patient rooms and special treatment rooms could have a higher turnover demand during an epidemic), this time savings could become a critical component in safe, effective patient management.

Table 20 reports the PTEs for the various nonpatient sample positions calculated with the GMRRs reported in Table 19. Note that across all four sites, the PTE for areas outside the source isolation zone ranged from 65 to 104 minutes, with a mean PTE of 87 minutes. Even if the lower 90 percent confidence limits of the GMRR were used for the PTE determination, the lowest PTE for these areas across the four sites would still be almost 45 minutes. These PTE values represent substantial time delays that healthcare workers and other staff would otherwise have while waiting for the same level of airborne concentration reductions offered by the expedient isolation configurations.

Table 20. Protective Time Equivalent (minutes) provided by concentration reductions generated by the zone-within-zone expedient isolation configurations.

Sample Position	VAMC		CKMC		SJMH		IBMC	
	2:1	3:1	2:1	3:1	2:1	3:1	2:1	3:1
HCW Upstream	2	3	93	74	4	12	93	93
HCW Dnstream	---	---	39	74	3	15	83	104
Outside Gap 1	93	104	93	74	77	71	93	93
Center Room	104	104	104	93	83	83	79	83
Outside Gap 2	74	87	104	104	66	87	93	87
Bed 2	65	87	104	83	65	71	93	83

Notes:
HCW = healthcare worker
VAMC = VA Medical Center
CKMC = Central Kansas Medical Center
SJMH = St. Joseph Memorial Hospital
IBMC = INTEGRIS Baptist Medical Center.
The horizontal double line at mid-table separates samples collected within the source isolation zone from those collected outside of this zone.

Ventilated Headboard Configuration

Evaluation of the aerosol spectrometer results from the ventilated headboard expedient isolation field studies may be similar to that of the zone-within-zone data discussed above. Tables 21 and 22 represent the GMRRs (with 90 percent lower confidence limits) and the calculated PTE, respectively.

Table 21. Summary of geometric mean reduction ratios (lower limits in parentheses) for the ventilated headboard expedient isolation field studies, simultaneously corrected for $\alpha = 0.10$.

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

Notes:
HCW = healthcare worker
RHS = patient's right-hand side
LHS = patient's left-hand side
VAMC = VA Medical Center
CKMC = Central KS Medical Center
SJMH = St. Joseph Memorial Hospital
IBMC = INTEGRIS Baptist Medical Center
yellow highlight/bold font indicates GMRR below 0.90.

Across the four field study locations, 40 of 40 calculated GMRRs exceeded the previously discussed 0.90 performance criterion, with results ranging from 0.92 to 1.00. Even among the lower limit determinations, only two (highlighted in yellow) were beneath 0.90, and both of these were results collected from the same patient chest position, located only inches from the source discharge point and not typical of a potential exposure location. Center room reduction ratios all exceeded 0.995, with the worst performing lower limit calculated at 0.980. Similarly, 15 of 16 GMRRs observed at the two worker positions exceeded 0.995, with the worse performing worker position reduction providing a GMRR of 0.987 and a 90 percent lower limit of 0.947. Given the similar GMRR estimates and largely overlapping confidence intervals, no meaningful difference in performance results is apparent between the 2:1 and 3:1 reduction ratios.

Decay curve analysis for the ventilated headboard results is not possible because the expedient isolation configurations worked so well that there was insufficient contaminant to allow decay monitoring. However, under real world scenarios, should patient movement or worker activities lead to contaminant escape from the inner zone (hood area), the high ventilation rate offered by the filtration unit would still serve to dilute the contaminant concentration in a manner consistent with that provided by an engineered AII room.

Similar to the zone-within-zone analysis, the EIPF can be calculated for the ventilated headboard isolation configurations; however, GMRRs reported equal to 1.0 must either be slightly decreased or carried out to additional decimal places to their true value (<1.0) in order for the EIPF formula to apply. Across the four study sites, calculated EIPF estimates for the center room and healthcare worker positions range from 77 (almost 8 times the assigned protection factor of 10 that OSHA applies to half-faced respirators) to 1000, with lower limits ranging from 19 to 333.

Table 22 reports the PTE for the nonpatient sample positions, calculated with the GMRR point estimates in Table 21. These sample positions represent locations of potential exposure to healthcare workers and/or other room occupants (cleaning staff, visitors, etc.). Across all four sites, the PTEs at these locations ranged from 65 to 104 minutes, with a mean PTE of 88 minutes. Even when the lower 90 percent confidence limits of the GMRR were used for the PTE determination, the lowest PTE for these sample positions across all four sites was again almost 45 minutes.

Table 22. Protective Time Equivalent (minutes) provided by concentration reductions generated by the ventilated headboard expedient isolation configurations.

Sample Position	VAMC		CKMC		SJMH		IBMC	
	2:1	3:1	2:1	3:1	2:1	3:1	2:1	3:1
HCW Upstream	65	83	104	87	93	87	93	93
HCW Dnstream	87	83	93	93	93	93	104	93
Center room	87	104	87	83	87	93	104	87

Notes:
HCW = healthcare worker
CKMC = Central Kansas Medical Center
IBMC = INTEGRIS Baptist Medical Center.
VAMC = VA Medical Center
SJMH = St. Joseph Memorial Hospital

IH Sampling / Optical Particle Counting

As discussed in Chapter III, the zone-within-zone field study at VAMC was the first of the expedient isolation field studies. During a cursory review of the results from this study, concern arose regarding the potential for unknown-source aerosol to interfere with the highest levels of performance determination. This was partially fueled by an awareness of construction activities occurring directly above the test room. Additional reasons for the concern were the GMRRs and increased variability at the “Outside Gap 2” and “Bed 2” sample positions, compared with those outer-zone sample positions that were closer to the source itself. One way to determine the presence of an unknown source was to compare the size distributions of airborne particles at the Bed 2 and source-vicinity sample positions. Figure 41 compares the airborne aerosol size distributions for the Bed 2 sample position and

an unlabeled Grimm spectrometer placed near the HEPA inlet within the source isolation zone. (The latter Grimm was placed there for troubleshooting purposes and not useable in the reduction ratio performance evaluations.) The size distributions were clearly different and appeared to indicate that the aerosol under observation at the Bed 2 position had an additional aerosol source with size characteristics inconsistent with that being generated within the source isolation zone.

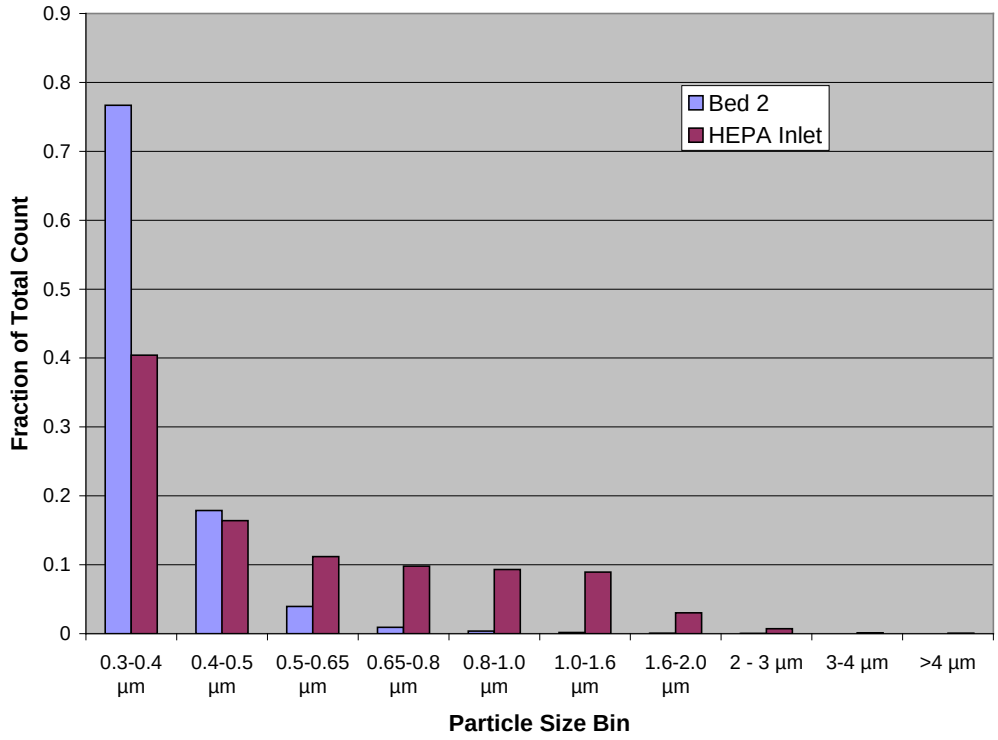


Figure 41. Size distribution comparison of aerosol observations within the source isolation zone and at the Bed 2 sample position in the zone-within-zone expedient isolation field study at VA Medical Center, Oklahoma City, OK.

The IH sampling/optical particle counting method was added to the field study protocol during the third individual field study, a ventilated headboard field study at Central Kansas Medical Center. The final protocol was not yet available for the two prior field studies (zone-within-zone studies at CKMC and VAMC). As a newly developed method, its intended role was limited to being a backup source of contaminant control information for potential use when equipment errors, unknown aerosol sources, or other issues brought the aerosol spectrometer data into question. For reasons discussed below, the method was only partially successful in this role, offering potential explanation for slightly reduced performance (Position A GMRRs of 0.987 [Grimm] vs. 0.999 [IH/optical]) at the VAMC ventilated headboard study, but of little use for examining performance questions from SJMH or CKMC.

One of the key concerns with the IH filter/optical count sample protocol was associated with the on/off timing of the IH sampling pumps. The IH pumps had to

be started and stopped manually. Upon starting the pump, the researcher left the room and shut the door to allow time for the HEPA unit to "clean" the room air before starting the nebulizer source. Room re-entry did not occur until after the nebulizer source had been stopped and the HEPA filter had again been used to clean the room air. Data from these cleaning periods could be excluded from the Grimm spectrometer output file, but the IH sampling method produces an integrated sample that, in this case, included the two air cleaning periods. Any airborne PSL spheres originating from the nebulizer source (after shut-off) or generated during setup between test conditions could be captured on a filter and thus hold a greater potential to bias performance results. Use of sample pumps with remote control start/stop or programmed sample periods could have eliminated this sampling issue.

Results from the IH/optical particle counting method are included in Appendix C. The GMRRs for the optical counting data were calculated from these data and were previously reported in Chapter III alongside the Grimm spectrometer results from the same respective sampling locations. Generally, the IH results tracked consistently with those generated by the aerosol spectrometer data, with over 78 percent of the IH/optical GMRRs falling within 1 percent of their Grimm-based counterparts. Overall, when compared with the corresponding Grimm spectrometer results from the same sample positions, 27 of the IH/optical GMRRs were higher, 30 were lower, and 2 were the same. Although this appeared somewhat evenly distributed, closer examination revealed an interesting trend regarding HVAC design. Room tempering for both VAMC and IBMC hospital rooms relied upon central HVAC systems, whereas tempering at both SJMH and CKMC relied upon room recirculating units. The breakdown comparing IH/optical results with their corresponding Grimm results revealed that for rooms with central HVAC systems, 26 of 30 IH/optical results were higher than their Grimm counterparts, 2 were lower, and 2 were the same. This seemed to indicate that for most sample positions, the Grimms were "seeing" particles that were not originating from the nebulizer. Despite this apparent trend, 29 of 30 IH/optical GMRRs from these two hospitals were within 0.5 percent of the Grimm-based results, indicating very good consistency between methods. For the SJMH and CKMH rooms with room recirculating units, 29 of 30 IH/optical results were lower than their corresponding Grimm-based results, and the differences in the results were slightly wider, with only 6 of 30 IH/optical results within 0.5 percent of their corresponding Grimm-based counterparts. This appeared to be an artifact of the field protocol, whereby coarse prefilters and internal surfaces of the recirculation units became contaminated during control-off runs and subsequently became aerosol generators (outside of the source isolation zone) during control-on test runs. This was not an indictment of the expedient isolation configurations under study, but it did raise potential safety questions regarding patient rooms with recirculating units being used as surge isolation rooms, without the assistance of a direct source control intervention.

Impact of 0.03 Baseline Shift

One unintended benefit brought about by the IH sampling/optical count method was the ability to evaluate the impact of the 0.03 baseline shift that was performed

on the count data prior to the log-transformation. In three of the field studies (SJMH 1-Bed, SJMH 2-Bed, and CKMC 1-Bed), there were no zero values in the IH/optical count data. For comparison purposes with these data sets, the Proc Mixed statistical model was applied both with and without the .03 baseline shift mentioned in the data analysis protocol. This allowed a direct comparison of the computed lower reduction limits to determine what effect the baseline shift may have had upon the determinations. This comparison and the differences in the numerical values are shown for the CKMC 1-Bed data set in Table 23. These results, showing minimal to no impact upon lower reduction limit computations, were consistent with those across the three applicable field studies.

Table 23. Comparison of lower geometric mean reduction ratio limits (Redu Lim; $\alpha = 0.10$) for the CKMC IH sampling/optical counting results, with and without 0.03 baseline shift (BLS).

Loc/Cond.	Correction	Redu_Lim w/ BLS	Redu_Lim w/o BLS	Delta
loc a con 3	Indiv.	0.968	0.967	0.001
loc b con 3	Indiv.	0.989	0.989	0
loc d con 3	Indiv.	0.974	0.973	0.001
loc e con 3	Indiv.	0.979	0.979	0
loc a con 2	Indiv.	0.985	0.985	0
loc b con 2	Indiv.	0.99	0.99	0
loc d con 2	Indiv.	0.989	0.989	0
loc e con 2	Indiv.	0.97	0.97	0
loc a con 3	Simul.	0.957	0.958	-0.001
loc b con 3	Simul.	0.984	0.985	-0.001
loc d con 3	Simul.	0.962	0.963	-0.001
loc e con 3	Simul.	0.974	0.975	-0.001
loc a con 2	Simul.	0.982	0.983	-0.001
loc b con 2	Simul.	0.988	0.989	-0.001
loc d con 2	Simul.	0.986	0.987	-0.001
loc e con 2	Simul.	0.965	0.966	-0.001

HEPA Fan Motor Impact Upon Room Temperature

Across the six field studies for which there were temperature data (all but SJMH), there was minimal evidence of increasing temperature trends during HEPA-On test

conditions. For three of the field studies, temperatures during HEPA-On test runs predominantly remained flat or actually decreased over the majority of the evaluated test periods. In two other studies, there was no predominant temperature trend, with slight temperature increases equally offset by flat to slightly decreasing temperatures. In one field study (CKMC 1-Bed), the overall temperature trend was slightly upward for all of the evaluated HEPA-On conditions; however, the magnitude of the increase was consistently small (1–1.5°F), and increases also occurred during 2 of 3 HEPA-Off test runs, indicating the temperature trends may have been predominantly driven by external environmental factors. Furthermore, the overall room temperatures remained below the ASHRAE-recommended upper design temperature. Thus, the HEPA fan would not be anticipated to adversely affect room environmental factors under the studied conditions.

Physical Parameters

Although other expedient isolation configurations offering varying degrees of airborne isolation and worker exposure reductions may exist, the following discussion reflects the findings and lessons learned from the subject research as discussed in this document. No claims are intended or implied regarding performance comparisons with configurations not tested under this protocol.

Zone-Within-Zone Configuration

The zone-within-zone subset of this research effort evaluated the creation of expedient isolation configurations with use of cabinet-type portable HEPA filtration units as the source of negative pressure and air cleaning. Within healthcare facilities, these cabinet-type portable HEPA filters are already used in an expedient fashion to either augment older AII rooms or provide some level of airborne isolation capacity when a sufficiently engineered AII room capacity is lacking. Although preference would be to place potentially infectious patients within private rooms, this may not always be possible. The zone-within-zone expedient isolation configuration research was intended to demonstrate the feasibility of cohorting infectious patients without sacrificing contaminant containment or subjecting healthcare workers and other room occupants to large-area “hot zones” of infectious contaminant.

To utilize the zone-within-zone expedient isolation configuration, healthcare facilities should first ensure that their portable HEPA filtration unit has the volumetric flow capacity to provide roughly 12 or more ACH, based upon the entire volume of the patient room. Preferably, the output of the HEPA units should be checked with a handheld aerosol counter to verify that the HEPA filter is installed and performing correctly.

*Inner Isolation Zone***:** Boundaries to the inner isolation zone can be established by using the patient room’s existing curtain track. In this manner, the resulting patient areas are consistent with those dictated by design standards in effect at the time of the healthcare facility’s construction. Medium-weight (3.5 to 4-mil) plastic sheeting worked effectively as the curtain or zone barrier material during the discussed field studies. Note that some jurisdictions may require use of fire-retardant plastic

sheeting. When room configurations require construction of an exhaust corridor between the two inner isolation zones, a framed corridor such as that used at IBMC is recommended as an effective option that reduces influence upon the adjacent inner isolation zone boundaries.

Flow Orientation: Flow orientation will likely be dictated by the patient room configuration. Whereas both the corner-to-corner and side-draft airflow orientations showed effective containment (GMRRs of 98–99 percent or greater) of source aerosol within the inner isolation zones, the side-draft orientation also provided significant contaminant concentration reductions inside the inner isolation zone, including GMRRs exceeding 99 percent (90 percent lower limits range: 97.1–99.3 percent) at the upstream healthcare worker positions. Thus, the side-draft orientation is preferable as long as it is compatible with room configuration and the anticipated requirements for hands-on healthcare. Regardless of the chosen orientation, use of plastic “bed ruffles” to reduce ineffective airflow beneath the bed surface is advisable. Qualitative flow checks and streamline observations conducted with tracer smoke should be regularly performed. Results from these checks should be shared (possibly through the use of floor markings) with attending healthcare workers so they will be familiar with ideal and nonideal locations in which to stand.

Curtain Gaps: Unlike engineered AII strategies that go to great lengths to minimize air leakage into the isolation zone, the zone-within-zone expedient isolation strategies intentionally use large volumes of incoming air and strategically designate the point of entry through the placement of the curtain gap. The incoming air is intended to enter the inner isolation zone through this gap, pass over the source, and carry the contaminant toward the HEPA filter inlet. As previously indicated, this approach was successful for the side-draft airflow configuration. However, the qualitative smoke test protocol provided only minimal success in producing direct capture streamlines at the two field studies which required corner-to-corner airflow configurations. Velocity determinations into the gap were hampered by wide variations of flow velocities across the height of the entrance gaps and by individual measurements that were often below the 30-fpm reliable detection limit of the handheld anemometer. At two locations, velocity determinations relied solely upon calculated values as opposed to a centerline velocity traverse with the anemometer. The American National Standards Institute (ANSI) Standard Z9.5 *Laboratory Ventilation* recommends a minimum flow velocity of 50 fpm through openings that lead into negative pressure containment areas within laboratories [ANSI/AIHA 2003]. Using this precedent, healthcare facilities choosing the zone-within-zone expedient isolation configuration should calculate the curtain gap width necessary to produce an average of 50 fpm entrance velocity, based upon the HEPA filter flow rate. Reducing the height of the curtain gap height may facilitate this process. The 50-fpm calculated gap width should then be used as the starting point for the qualitative smoke test protocol. The final selected gap width should be that closest to the 50-fpm gap width that also produces flow streamlines that flow over the patient source and toward the HEPA filter inlet. If circumstances such as a corner-to-corner airflow configuration prevent the clear identification of source-capturing streamlines, then deviations from the 50-fpm gap width would not be necessary.

HVAC Supply Louvers: The makeup air supply into the inner isolation zone should rely primarily upon airflow entering through the curtain gap. HVAC supply points should preferably be located outside of the inner isolation zone in order to maximize dependence upon the curtain gap as the source of airflow into the isolation zone and to minimize the potential for interrupting air currents. When this is not possible, curtain deflectors should be employed to minimize the interruption potential of the HVAC air supply with the contaminant-carrying airflow streamlines**.** If the HEPA filtration unit has the additional airflow capacity, increasing the HEPA airflow rate above the room's 12 ACH setting can help to offset any HVAC-induced reduction of airflow through the curtain gap. Recirculating terminal units and HVAC return grilles should be avoided within the inner isolation zone. When unavoidable, they should be sealed or otherwise isolated to prevent recirculation of airborne contaminants from within the inner isolation zone.

Ventilated Headboard Configuration

The ventilated headboard subset of this research effort evaluated the ability to employ industrial ventilation-type control strategies in combination with ducted portable HEPA filtration units, typical of those used for contamination containment during construction or asbestos abatement activities. These units are commonly used during hospital renovation activities in an effort to reduce distribution of mold spores and construction dusts into occupied areas of the facility. In the current research, this configuration was evaluated in single-patient rooms only.

HEPA Flow rates: As with the zone-within-zone configuration, the targeted minimum flow rate for the portable HEPA units was that necessary to provide 12 ACH, based upon the entire volume of the patient room. In addition to this volumetric flow rate criterion, the airflow into the ventilated headboard/hood combination required sufficient velocity to overcome room air currents without placing the patient's head into a "wind tunnel" of excessive air velocity. Balancing these two requirements, a minimum average flow rate of 30 fpm into the hood was also a design target that impacted the final flow rate through the HEPA filtration unit. Preferably, the outputs of the HEPA units should be checked with a handheld aerosol counter to verify that the HEPA filter was installed and performing correctly.

Headboard Dimensions: Headboard size dimensions were determined on the basis of bed dimensions, the adjustable range of the bed incline, and the ability to provide inward and outward visual access from within the hood. Because of consistent bed dimensions and operation, a 2-ft by 4-ft ventilated headboard was the chosen dimensions across all four of the ventilated headboard field sites. Hood static pressure measurements of a 2-ft by 4-ft ventilated headboard, constructed with 1-in by 4-in dimensional lumber, MERV 7 prefilters, and a 6-in-diameter duct take-off revealed a hood static pressure requirement of -2.0 in water gauge (w.g.) when operated at 240 cfm (30 fpm average face velocity). Although such a hood was not used at any of the field study locations, laboratory construction and evaluation of a similarly constructed hood built with 1-in by 6-in dimensional lumber required a hood static pressure of only -1.0 in w.g. when operated at the same airflow rate.

Hood Depth: Hood depths were determined with a qualitative tracer smoke protocol targeted to identify the minimum hood depth (D_0) at which smoke escape was not visible. For purposes of the experimental protocol, two hood depths were selected, D_0 and D_0 + 8 in. Though the 8-in increment in hood depth was somewhat arbitrarily determined for evaluation, the D_0 + 8-in hood depth generally approximated the 75 percent of largest dimension rule-of-thumb practiced in industrial ventilation design. A review of the ventilated headboard GMRR performance summary in Table 21 shows that the results for Condition 2 (hood depth at D_0) and Condition 3 (hood depth at D_0 + 8 inches) were very similar, with GMRR estimates within a single percentage point of each other for 19 of the 20 sample position/field study combinations. The one outlier was a chest position sample at CKMC which, due to its proximity to the source, is of limited value in regards to worker exposure predictions. When considered in combination with the GMRR 90 percent lower limits, none of the sample results showed a significant difference in performance between Condition 2 and Condition 3. Though these results appear to demonstrate that the qualitative tracer smoke protocol as used in the research was successful in identifying a successful hood depth, the qualitative nature of the protocol is subject to human error if conducted by less experienced individuals. For this reason, the 75 percent of widest dimension rule-of-thumb is recommended as the starting point for conducting the tracer smoke hood-depth protocol, with modifications to this hood depth made only if supported by improved tracer smoke containment.

HVAC Interaction: Interaction of the HVAC system with the function of the ventilated headboard expedient isolation configuration was less of an operational factor than with the zone-within-zone configurations. Only one field study site required supply air deflection in order to avoid interference with airflow streamlines within the vicinity of the hood entrance. In general, locating patients immediately adjacent to or beneath HVAC supply louvers should be avoided. Decisions regarding HVAC return air grilles should be situation-specific and take into consideration HVAC factors (e.g., level of filtration, return air requirements in order to avoid starving the system of sufficient return air) and infection control policies. If the HVAC system recirculates back to the same room only, there is probably no need to block the HVAC return. If it recirculates to a zone consisting solely of potentially infectious patient rooms, the zone might be treated as an infectious cohort patient area and the return grilles left open. If the HVAC zone includes both AII and non-AII areas, return air grilles from the AII areas should probably be blocked or limited to HEPA filtered air only. Healthcare facility infection control planners should remember that if return air grilles are blocked and HVAC air supplies remain open, the room will generally become positive and will leak air. Under these circumstances, if the HEPA discharge can be the source of the leaked air, this will reduce the potential for contaminated air to migrate from the expedient AII patient room.

Chapter V

Summary

Background

Although the nature of an applied research effort conducted within multiple real-world settings generally precludes the ability to tightly control the test environment, the results can provide a realistic insight into the expectations and obstacles that could assist in the potential transition from research to practice. In the expedient isolation field research, the research objectives included:

- The identification of “universal designs” applicable to real-world healthcare environments;
- The development of test protocols that challenged the containment and exposure reduction effectiveness of the evaluated configurations using aerosol theory and airborne infectious-sized surrogate contaminant generation;
- The documentation, evaluation, and interpretation of the performance of the tested configurations in ways which will add meaning to their potential end user.

The study limited its evaluation options to affordable and easily constructed alternative(s) to traditional engineered AII rooms that might be used in an emergency surge capacity for AII following a natural or manmade epidemic event. The motivation for the research was a well-documented acknowledgment of insufficient engineered airborne infectious capacity within the U.S. healthcare system. This coincided with an increased awareness of the threat demonstrated by increased terrorism concerns, recent experiences with SARS, and the ongoing evolution of influenza virus strains that could become airborne infectious. Without expedient, cost-effective options such as those discussed in this research, the alternatives, as already disseminated in numerous guidance documents, will be an abandonment of many AII practices, patient cohorting within large “hot zones” of potential airborne infectious aerosol, and hopeful expectations of healthcare worker protection from airborne infectious aerosol resulting primarily through the use of N95 respirators or even surgical masks.

Research Methodology

Before expedient design configurations identified during the feasibility study could be sufficiently challenged, a technique was needed for generation of surrogate airborne infectious-sized aerosol contaminant. The surrogate source generation technique required the ability to produce repeatable aerosol generation rates. This was accomplished through the development of a HEPA-filtered wind tunnel, modified to allow upstream injection of the output from a medical nebulizer whose dosing fluid was crafted to minimize conglomerate generation. The use of batch source mixing of the dosing fluid resulted in the repeatability characteristics necessary to conduct comparative particle count determinations between tested interventions and their noncontrol counterparts.

Two expedient isolation configurations, zone-within-zone and ventilated headboard, were evaluated in each of four Midwestern hospitals, for a total of eight field studies. The hospitals were chosen on the basis of their willingness to participate in the study and the fact that they collectively represented a wide spectrum in terms of facility size and design. The research protocol used a randomized (complete) block design of two levels of intervention plus one noncontrol test condition, with a caveat that once a test order of conditions was utilized within a block, that same order could not be repeated in a subsequent block. Analysis of data from an early field evaluation revealed diminishing returns to be gained by conducting more than six blocks, and given the three test conditions, the six-block strategy allowed any order-associated bias to be evenly distributed across the field study results. Qualitative tracer smoke protocols were incorporated in establishing several of the field configuration parameters at each hospital prior to initiation of the quantitative evaluation.

The primary aerosol count data were collected with aerosol spectrometers, with a focus on particle counts within the size bin of the source aerosol. Data manipulations, including background correction, a small baseline shift, and log transformation, were performed within SAS, and the mean of each test run's log-transformed count value became the representative test result for analysis in SAS Proc Mixed. Model results were reported as a GMRR and lower 90 percent reduction ratio confidence limits between each of the tested interventions and the noncontrol test condition. Additional aerosol count data were collected with IH filter sampling techniques, combined with a newly developed optical counting method. The new method was introduced after initial field studies, as a backup evaluation method in the event of excessive environmental background contamination.

Major Findings

Aside from ignored sample results from the chest position adjacent to the source, the evaluated expedient airborne isolation configurations were universally successful (GMRRs of 98–99 percent or greater; 90 percent lower limits range of 94.2–99.9 percent) in their ability to contain surrogate infectious aerosol within the inner isolation zones (including within the ventilated headboard's receiving hood). Center-of-room sample results across all sites and configurations resulted in GMRRs ranging from 99.5 to 99.9 percent and 90 percent lower limits ranging from 97 to 99.6 percent. Worker exposure reductions were more variable. There were no meaningful (GMRR lower limits ranging from negative to under 10 percent) real-time exposure reductions associated with the two corner-to-corner/zone-within-zone isolation configurations under the evaluated test conditions; however, these areas still benefited from the increased dilution at a set ventilation rate that resulted from the smaller isolation zone. For the two side-draft/zone-within-zone configurations and all of the ventilated headboard field studies, GMRR results observed for healthcare worker positions not located in known exhaust paths ranged from 98.7 to 99.9 percent, with lower 90 percent limits ranging from 94.7 to 99.6 percent. Across all of the isolation configuration field studies, similar GMRRs with overlapping confidence intervals indicated no significant difference between the Condition 2 and Condition 3 test conditions. Analysis of temperature log data revealed either no impact to environmental conditions based upon HEPA fan

function or insignificant impact in regards to moving room temperatures outside of the ASHRAE-recommended temperatures of 70–75°F.

Implications

Given the important role of healthcare providers in responding to an airborne infectious epidemic and the lack of engineered airborne isolation capacity within the U.S. healthcare inventory, the findings of the present study could have important implications for U.S. healthcare emergency planning policies. Some of these are discussed in the following paragraphs.

Polling data have shown that as few as 24 percent (worst-case combination of willingness and ability) of healthcare workers within the greater New York area were willing to report to work unscheduled, in support of an infectious airborne epidemic such as SARS [Quereshi et al. 2005]. Fear regarding personal and family safety was the primary driving factors. These results are consistent with findings of an Israeli study involving medical response to an unconventional missile attack. However, in that study, healthcare worker willingness to report increased from 42 to 86 percent if personal safety measures were available [Shapira et al. 1991]. Given the previously reported experiences with healthcare worker exposures and SARS, these reported fears are probably justified, as is the need to identify worker-protective surge isolation strategies. The results of these polling data are also consistent with the real-world U.S. outbreak of monkeypox in 2003. In that circumstance, several physicians and nurses declined to provide patient treatment or engage in direct patient contact, some claiming a lack of smallpox vaccination and others without explanation [Anderson et al. 2003].

Expedient isolation interventions, such as those discussed in this research, that result in workplace protection factors several times greater than that expected for N95 respirators could provide additional reassurance to healthcare workers responding to airborne infectious or even unknown events. In a long-term incident, where respiratory protection shortages could exist and reuse strategies were implemented, the reduced loading on the outside of the respirators could also result in decreased disease transmission. Healthcare administrators, physicians, and others involved in workforce/bed/patient management could also benefit from the subject research through use of the protective time equivalent (PTE) determinations to reduce the amount of waiting time considered for safe entry into patient areas (patient rooms, ambulances, operating rooms, special treatment rooms, autopsy rooms) potentially contaminated by individuals with known or suspected airborne infectious disease. Depending upon the room type (for example, emergency department patient rooms and special treatment rooms could have a higher turnover demand during an epidemic), this time savings could become a critical component in safe and effective patient management.

As information is disseminated concerning the cost-effective contaminant reduction capabilities of the expedient isolation interventions developed and evaluated as part of this research progress, the potential to impact evolving emergency response policies and budgets will increase. Preliminary portions of this research have already been incorporated within a Minnesota Emergency Response Education and

Training (MERET) Learning Module titled *Methods for Achieving Temporary Negative Pressure Isolation (TNPI)* [University of Minnesota 2006]. Final research results and recommendations may also be developed for publication within a general guidance document (non-disease-specific) on expedient AII to be published by the National Institute for Occupational Safety and Health (NIOSH), of the Centers for Disease Control and Prevention (CDC).

Lastly, the findings from this research coincide with heightened public awareness of the need to protect healthcare workers from unnecessary exposures and also at a time when discussions on energy conservation and "green design" are on the engineering forefront. The effectiveness of the direct-capture approaches to contaminant isolation exhibited by the researched expedient isolation designs, when compared to the equivalent time delays and energy expenses associated with engineered AII rooms that rely on single-pass dilution, could encourage new discussion on the design and operation of engineered AII rooms.

Limitations

The expedient AII configurations studied under this research effort are intended as emergency response alternatives to surge demands for AII. Care must be taken that the results not be interpreted as championing the use of expedient isolation configurations in lieu of engineered AII room capacity.

As studied, the methodology was a randomized (complete) block design that focused upon testing the isolation configurations within real-world settings. Access to hospital sites, length of access, and the time and expense associated with the field studies limited the number of variables that could be evaluated and the depth of their investigation. Alternatively, efforts to obtain comparative results regarding issues such as hood depth or tolerance to nearby HVAC diffusers may have been more definitively defined had the research been conducted in a mocked-up laboratory environment where environmental parameters could be better controlled. In addition, a laboratory-based setting could have allowed investigation of additional variables (e.g., bed inclination and healthcare worker body position) through the use of larger block sizes or by incorporating an incomplete block design that used additional blocks. Of course, translation of findings resulting from a lab-based investigation would then require further investigation within real-world environments, and that translation may or may not have been completely successful.

One of the issues that will challenge acceptance of the expedient isolation approaches mentioned in this research is the paradigm shift away from insisting that the entire patient room be under negative pressure relative to the adjacent corridor. One approach that could circumvent this obstacle would be to direct the discharge from the HEPA filter units to create a positive-pressure anteroom near the patient room entrance. In this manner, facility personnel could still perform regular smoke tests (from the anteroom) to verify inward airflow into the patient area, and the anteroom could also serve as a "safe area" for donning and doffing protective gowns and respirators.

Like most interventions, the effectiveness of the discussed expedient airborne infection isolation strategies can be thwarted by improper work practices. While the operating concepts of these intervention strategies were proven to be tolerant of the airflow interferences encountered in the real-world healthcare environment in which they were evaluated, it is intuitively plausible that the protective features could be diminished through poor work practices. Practices that might interfere with the directional airflow and containment strategies, such as improper placement of portable fans or interfering with the integrity of containment curtains, should be avoided. The careful use of qualitative tracer smoke, as described in this report, can be a helpful evaluation tool to help identify and eliminate such potential interferences.

Suggestions for Further Research

The importance of the expedient isolation research as applied to natural or manmade emergency response scenarios, combined with the myriad influences that constitute healthcare facilities' operation and design, lead to several potential areas of further research. Some of these are discussed in the following paragraphs and are in no particular order of importance.

Bed Position

Although cursory checks of bed inclination against capture performance were conducted extemporaneously in the field, such an evaluation was not part of the research protocol. If only to resolve potential questions, the issue of bed inclination as it relates to capture performance and resulting GMRRs is one that could benefit from additional research.

Worker position / worker movement

Similarly, an obvious question remains regarding the positioning and movement of healthcare workers and the potential impact upon airflow streamlines and resulting contaminant capture. Although escaping contaminant under these circumstances would still be subject to the protective benefits of the 12 ACH of dilution filtration, the potential performance reduction in terms of real-time concentration reductions is a legitimate research question.

Comparison Temporary Negative Pressure Isolation

One commonly identified approach to expedient airborne isolation to meet surge requirements is the establishment of Temporary Negative-Pressure Isolation (TNPI) areas. These areas, which more closely follow the theory behind traditional engineered AII rooms (6 to 12 ACH and negative pressure), are often constructed through the use of portable HEPA filtration units whose discharge has been directed to the outdoors [University of Minnesota 2006]. A criticism of TNPI units is that their impact, especially if multiple units are required, upon HVAC system operation and adjacent room pressures is not always well-understood. In theory, these questions should be evaluated prior to wide-scale adoption of TNPI in an emergency response plan. One research comparison of interest would be to compare room and worker position concentration reductions resulting from TNPI interventions with

those provided by the expedient isolation configurations considered in the current research.

Combining Ventilated Headboard and Zone-Within-Zone Configurations

The ventilated headboard configuration showed an excellent capability to capture and remove airborne contaminant; however ,this performance may well be positionally specific (i.e., the source is within the vicinity of the headboard and hood). Combining the capture benefits of the ventilated hood with the additional capture protections and enhanced dilution characteristics of a smaller isolation zone could be an interesting isolation approach worth investigating.

Protective Isolation

The containment techniques used to construct engineered AII rooms are similar (with opposite pressure relationships) to those required for protective isolation environments. A surge of potentially immunosuppressed patients (such as what might occur following a widescale exposure to radioactive material) would require protective isolation (positive pressure) from airborne pathogens [Oak Ridge Institute for Science and Education 2004]. Intuitively, it seems the expedient isolation configurations should be modifiable to produce an expedient protective isolation environment. This alternative should be evaluated and proven before becoming part of an emergency response plan.

Nonhospital Environments

The expedient airborne isolation configurations discussed in this research were all constructed and evaluated within traditional hospital facilities. Variations of the same control techniques might provide protective benefits to a wide variety of nonhospital environments, some of which could play a key role in thwarting disease transmission during a widescale epidemic. Examples include nursing homes, doctors' offices, ambulatory transport, schools, jails, homeless shelters, transcontinental airplanes, and airport and border patrol quarantine stations. Research efforts that test and evaluate the use of these control techniques in these environments could facilitate national preparations for a potential airborne infectious epidemic.

Conclusion

The U.S. healthcare system lacks sufficient engineered AII surge capacity to meet the demands of a widespread airborne infectious epidemic. Some healthcare facilities, including two included as part of this research effort, lack the engineered AII room capacity to handle even a single airborne infectious patient. Government programs have begun spending billions of dollars to improve this engineered capacity, but at a government-predicted average of $500 million to upgrade a single major city, the time and resources required to sufficiently protect the entire U.S. healthcare system in both rural and urban environments is beyond the scope of any government program. Alternative solutions are needed to meet surge airborne isolation requirements. Some proposed "solutions" have included resorting to a heavy dependence on respiratory protection and the establishment of large "hot zones" of potentially infectious aerosol. The expedient airborne isolation

research discussed within this document has identified isolation configurations that rely upon inexpensive, off-the-shelf materials and HEPA filtration systems that are commonly found within healthcare facilities. Most provide better real-time source protection from infectious aerosol than that expected to result from an N95 respirator. In several cases, the protection is several times better. These findings are not intended to replace the respiratory protection guidance provided to healthcare workers; however; the additional reduction in contaminant concentrations will lessen the dependence upon the N95 as the last line of airborne defense. Healthcare workers need and deserve assurances that their safety will not be sacrificed in the name of emergency response. U.S. citizens share that need if they expect healthcare workers to report to work and to stay sufficiently healthy to provide treatment. While millions of dollars will continue to be spent seeking cures and immunizations for airborne and other infectious diseases, the objectives of this modest project and its identified interventions may be summed up in the words of Thomas Fuller (1608–1661), British clergyman and author: "*He who cures a disease may be the skillfullest, but he that prevents it is the safest physician.*"

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Appendix A

Copy of peer-reviewed journal article published from preliminary field study associated with this research.

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An Evaluation of Portable High-Efficiency Particulate Air Filtration for Expedient Patient Isolation in Epidemic and Emergency Response

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Extraordinary incidents resulting in airborne infectious disease outbreaks could produce patient isolation requirements that exceed most hospitals' capacity. This article investigates expedient methods to establish airborne infection isolation areas using a commercially available portable filtration unit and common hardware supplies. The study was conducted within a conventional, nonisolation hospital room, and researchers evaluated several airborne isolation configurations that did not require building ventilation or structural modifications. A portable high-efficiency particulate air filtration unit and full-length plastic curtains established a "zone-within-zone" protective environment using local capture and directional airflows. The cost of constructing the expedient configurations was less than US$2,300 and required fewer than 3 person-hours to construct. A medical nebulizer aerosolized polystyrene latex microspheres to generate respirable condensation nuclei. Aerosol spectrometers sized and counted respirable particles at the source patient and health care worker positions and in areas outside the inner zone. The best-performing designs showed no measurable source migration out of the inner isolation zone and mean respirable particle counts up to 87% lower at the health care worker position(s) than those observed directly near the source patient location. Investigators conclude that with careful implementation under emergency circumstances in which engineered isolation rooms are unavailable, expedient methods can provide affordable and effective patient isolation while reducing exposure risks and potential disease transmission to health care workers, other patients, and visitors.

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INTRODUCTION

Background

The health care burden during an infectious disease outbreak, such as the recent experience with severe acute respiratory syndrome (SARS), or a large bioterrorism event will fall disproportionately on health care providers at the local level. Hospital emergency departments (EDs), outpatient clinics, and even physician offices could be required to handle a surge of patients, many potentially infectious, others motivated by fear to seek medical care for their nonspecific "flu-like" or respiratory symptoms. In addition to providing patient care, health care facilities must also protect their patients, staff, and visitors from exposure to potentially infectious patients. Between April 15 and June 9,

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2003, 74 SARS cases were reported to Toronto Public Health. Of these, 29 (39%) of 74 were among health care workers, 28 (38%) of 34 occurred as a result of exposure during hospitalization, and 17 (23%) of 74 occurred among hospital visitors.[1] Under these scenarios, staffing shortages are probable, appropriate respiratory protection supplies will be in high demand, and the need to isolate potentially infectious patients will exceed the availability of airborne infection isolation rooms.

Importance

Although the US government has been working to address shortcomings in our emergency medical response plan for extraordinary incidents, feasible solutions that are applicable across multiple demographics have been slow to develop and appear costly to implement. Recent governmental reports indicate that the US health care system generally lacks the patient isolation capacity to handle a significant airborne infectious epidemic or bioterrorism event.[2,3] Attempts to identify alternative isolation approaches have had few details and much controversy.[4,5] Draft recommendations prepared by the Centers for Disease Control and Prevention (CDC) for community-level preparedness and response to SARS include a few references to the use of portable filtration units and other engineering controls to address surge-patient isolation requirements; however, more guidance is needed about their selection and effective use.[6]

Goals of This Investigation

The purpose of this work is to evaluate the potential feasibility of expedient, negative-pressure, high-efficiency particulate air (HEPA)–filtered patient enclosures for control of airborne pathogens during emergencies requiring isolation surge capacity. HEPA filters are at least 99.97% efficient in removing particles that are 0.3 µm (the size most difficult to capture) and essentially 100% efficient for particles either larger or smaller than 0.3 µm. The selection of portable filtration technology as an evaluated approach was fueled by its compatibility with existing ventilation systems, its affordability, and its recognition in published literature as an available engineering control to assist in patient isolation.[7-10] In particular, these references cite the use of portable filtration units as a way to increase the effective dilution of airborne contaminants within a designated airborne infection isolation room. By virtue of a "zone-within-zone" approach to configuring patient isolation areas, the researchers sought to improve on the traditional whole-room dilution approach to contaminant control by significantly increasing source containment and capture efficiency within a smaller inner isolation zone occupied by the patient. In this manner, contaminant spread to the remainder of the room (the outer zone) could be minimized, thus reducing health care worker exposure potential.

MATERIALS AND METHODS

Room Description and Isolation Zone Configurations

The performance of a free-standing, portable, HEPA filtration unit (Figure 1) as an aid to establish expedient airborne infection isolation areas was evaluated within a hospital room of roughly 2,500-cubic-foot volume (71 m^3). The room's floor space measured approximately 20×16 ft (6×5 m). The original room design accommodated 3 patient beds, with no provisions for airborne infection isolation. A restroom measuring approximately 5×10 ft (1.5×3.0 m) was connected to the patient room. The door to the restroom remained closed throughout the testing. For the patient isolation research, there were 2 evaluated configurations: a 2-patient configuration with independent isolation areas for each patient and a single-patient isolation configuration. Of the 7 trial scenarios evaluated during the study, 3 scenarios were variations of the 2-patient configuration, and 4 scenarios were variations of the single-patient configuration.

The same HEPA filtration unit (Model NU-114, NuAire Inc., Plymouth, MN; US$2,195.00) provided the air-cleaning capacity for each configuration. The existing cotton privacy curtains were removed from their tracks and replaced by floor-to-ceiling plastic curtains. In actual practice, the cotton privacy curtains could remain in place, and the plastic curtains could be mounted inside of the cotton. The plastic curtains were constructed from 4-mil plastic sheeting sold as painting drop cloth in home improvement and painting supply stores. The plastic curtains were mounted to within approximately 0.5 inch (1.3 cm) of the ceiling curtain track using the existing curtain hooks, thus retaining the curtain's ability to be completely opened and closed. The curtain extended 8 feet (2.4 m) downward to approximately 0.5 inch (1.3 cm) above the floor.

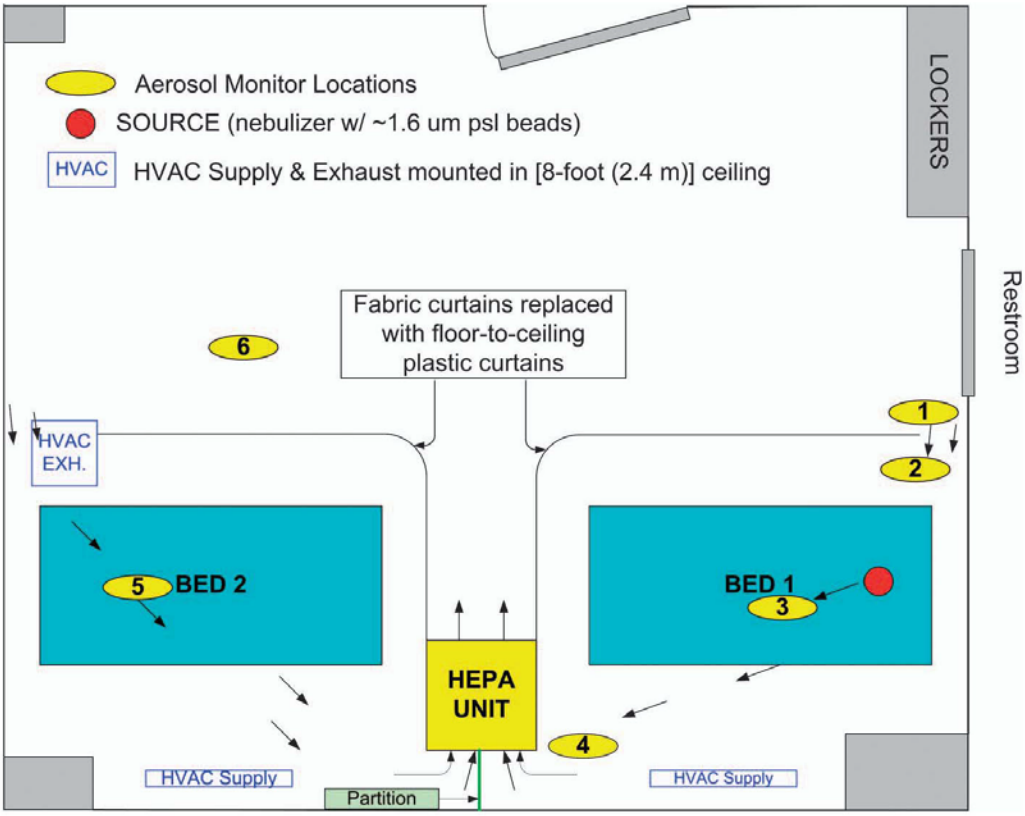
For the 2-patient configuration, the HEPA unit was placed equidistant between the footboards of the 2 patient beds and diagonally across from the entrance into the individual patient areas (Figure 2). The inlet perimeter of the HEPA unit was tightly secured to the 2 curtains using plastic sheeting and strips of sheathing tape. In this configuration, the HEPA unit pulled "contaminated" air

Figure 1.
Photographs of the NuAire portable HEPA filtration unit used in this work. A, The assembled unit viewed from the inlet side (cellular telephone shown for scale); B, inlet grille and one 2×2 ft (0.61×0.61 m) prefilter removed to show fan unit; C, rear view with exhaust grille removed to show the 4.5×2 ft (1.22×0.61 m) HEPA filter.

from the 2 patient isolation areas (inner zones) and discharged clean air into the remainder of the room (the common outer zone). After initial tests revealed a transfer of source aerosol between the 2 patient isolation zones, additional 4-mil plastic sheeting was used to construct a floor-to-ceiling vertical partition at the inlet-side of the HEPA unit to prevent such migration. A photograph of the inlet side of the HEPA unit showing the vertical partition, as well as the plastic curtains taped into place, is shown in Figure 3. To facilitate controlled airflow into the inner isolation zones, each curtain was retracted to create a gap approximately 10 inches (0.25 m) wide near the head of the respective patient beds where the patient care provider might frequently stand. The gap width selection was based on qualitative smoke tests using a handheld smoke generator (Cumulus Air Flow Indicator, Draeger Safety Inc., Pittsburgh, PA). This gap provided a strategic path of least resistance for air to enter the inner isolation zone and flow past the health care worker, over the patient, and toward the HEPA unit with minimal recirculation inside the enclosure.

In the single-patient configuration, the HEPA unit was placed near the wall at the foot of the patient bed and incorporated into the curtain boundary as shown in Figure 4. Additional plastic sheeting was taped around the HEPA inlet to form a tight seal between the plastic curtain,

Figure 2.
Schematic showing a 20×16 ft (6×5 m), 3-bed nonisolation hospital room expediently converted to contain isolation zones for 2 potentially infectious patients. In this configuration, a single HEPA filtration unit provides the air cleaning capacity for both isolation zones.



the wall, and the inlet perimeter of the HEPA unit. Because of the increased airflow within the single isolation zone, the entrance curtain gap was increased to 12 inches (30 cm) on the basis of results from the qualitative smoke tests.

Both configurations were designed to pull clean air into the inner isolation zone and into the space occupied by a bedside health care worker. The air path continued past the worker and across the patient position where the air became potentially "contaminated." The contaminated air from the inner isolation zone was pulled toward the HEPA unit, cleaned, and then discharged into the room's outer zone, thus maintaining the inner zone at a negative pressure relative to the outer zone and its adjacent areas. Smoke tests were conducted along the top and bottom edge of the plastic curtains to verify a consistent inward airflow.

Figure 3.
Photograph showing inlet side of the HEPA filtration unit located between 2 patient isolation zones. The vertical partition at the inlet grill successfully prevented source aerosol from transferring between the 2 isolation zones.

Airflow Measurements

Volumetric flow rates through heating, ventilating, and air conditioning (HVAC) supply air diffusers, exhaust grilles, and the HEPA unit were measured using an Alnor Electronic Balometer (Model APM 150, TSI Incorporated, Shoreview, MN). The balometer's 1×4-ft (0.3×1.2 m) extension hood was used to measure airflow rates through the HVAC supply diffusers and exhaust grille. The 2×4-ft (0.6×1.2 m) extension hood was used to measure the airflow rate on the discharge side of the HEPA unit.

Particle Control Measurements

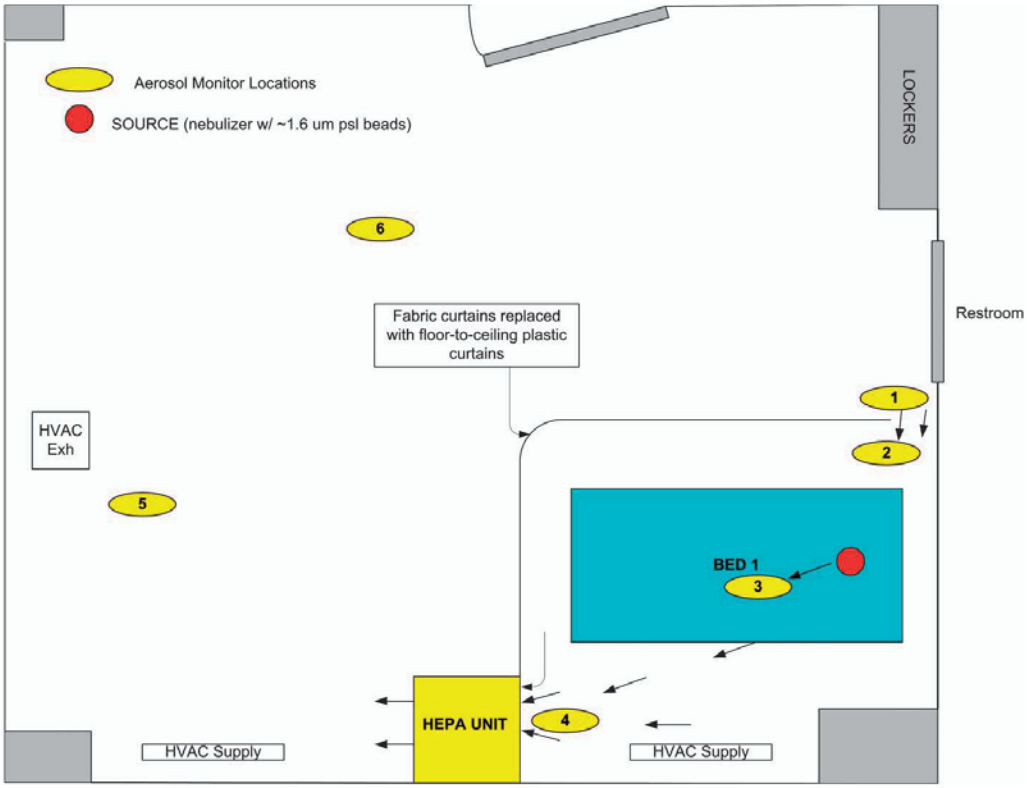
Uniformly sized polystyrene latex microspheres of 1.65-µm diameter (Catalog No. 4016A, Duke Scientific, Palo Alto, CA) were aerosolized as condensation nuclei originating from the patient 1 head position using a standard medical air-jet nebulizer operating at a pressure of 20 psi (138 kPa) (PARI Star nebulizer with ProNeb Ultra compressor Model 85B 0000, PARI Innovative Manufacturing Inc., Midlothian, VA). This particle size was chosen as being representative of the 1- to 3-µm size range of tuberculosis bacteria, spores (including anthrax spores), and other infectious bioaerosols that remain airborne for long periods, are readily inhaled, and penetrate deep into the lung.[11] The airborne particles were sized and counted at 3 locations inside of the source patient's (patient 1) isolation zone and 3 locations outside of this zone using real-time light-scattering aerosol spectrometers (Grimm Dust Monitors, Models 1.105, 1.106, and 1.108 [2 each], Labortechnik GmbH & CoKG, Ainring, Germany). These monitors measure the aerosol size distribution in 8 size ranges. Results were logged in the form of particle counts per liter of air at a 1-minute sampling interval. For the purposes of this research, attention was paid to the size range between 1 µm and 2 µm, which corresponds to the 1.65-µm source aerosol. The aerosol monitors were located as shown in Figures 2 and 4 and placed at bed height (approximately 36 inches [91 cm] above the floor) except the provider position monitor inside the enclosure, which was placed at a height (60 inches [150 cm] above the floor) representing the breathing zone of a standing health care provider. Monitors outside the enclosure were placed at bed height to indicate the potential for exposure of other patients to particles escaping the enclosure.

Before the polystyrene latex microspheres were aerosolized, the HEPA unit was operated for 45 minutes with the restroom and entry doors closed to minimize background aerosol concentrations. Background concentrations were consistently reduced to less than

20 cpm for 1- to 2-µm particles. This concentration was generally 3% to 5% of the concentration produced near the aerosol generator at the patient head position during experiments. For each trial, the nebulizer cup was prepared by adding 3 drops of the suspended polystyrene latex microspheres into 8 mL of water purified by reverse osmosis (reverse osmosis water). After collection of at least 5 minutes of background readings, the nebulizer was activated and the airborne particle counts were logged throughout a 30-minute nebulization period. The collected particle count data were downloaded to a personal computer for archiving and analysis within an Excel spreadsheet (Microsoft Corporation, Redmond, WA).

In the 2-patient and single-patient configurations, multiple tests were performed incorporating several design and operational combinations associated with the HVAC supply diffusers and exhaust grille. When sealed, the linear HVAC supply diffusers were covered with tape. Similarly, the square exhaust grille was sealed with tape and plastic for all 2-patient configuration trials, where its location fell within patient 2's inner isolation zone. The exhaust was also sealed for 1 of the 4 single-patient configuration trials, even though it fell outside the inner

Figure 4.
Schematic showing a 20×16 ft (6×5 m), 3-bed nonisolation hospital room expediently converted to contain a single zone for a potentially infectious patient. In this configuration, the HEPA filtration unit is reoriented to serve the single isolation zone.



isolation zone, in recognition that despite the containment of the inner zone, some hospitals or jurisdictions may still not allow air recirculation from the overall room back into the general HVAC system.

DISCUSSION

Airflow

The HEPA unit's flow rate was measured at 550 cubic feet per minute (cfm) (0.26 m^3/s [cms]). Expressed in terms of air changes per hour, the unit provided more than 13 air changes per hour of filtration for the entire patient room (inner and outer zones) while providing more than 32 air changes per hour for the isolated inner zones of the 2-patient configuration and more than 65 air changes per hour for the isolated inner zone of the single-patient configuration. All of these values compare favorably with design recommendations provided by the CDC, the American Institute of Architects, and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, which prescribe at least 12 air changes per hour for engineered airborne infection isolation rooms, although for engineered rooms, they also prescribe at least 2 air changes per hour of outdoor air.[7-9,12] When open, the HVAC supply diffuser near patient bed 1 delivered 185 cfm (0.09 cms), the diffuser near patient bed 2 delivered 130 cfm (0.06 cms), and the exhaust grille removed 155 cfm (0.07 cms) from the room. The bathroom flow rates were 90 cfm (0.04 cms) of supply air and 125 cfm (0.06 cms) of exhaust air directed to the outdoors, resulting in more than 18 air changes per hour within the restroom while maintaining it under negative pressure. Thus, even within the restroom, the airflow values maintained consistency with the prescribed design recommendations for engineered isolation rooms.

Qualitative Smoke Tests

In addition to verifying airflow directions and assisting in the selection of the desired curtain gap, the qualitative smoke tests were instrumental in constructing and fine tuning the evaluated configurations. After the initial trial run in the 2-patient configuration revealed low-level source migration into the outer zone, qualitative smoke tests revealed that a stream of contaminated air, induced by the discharge side of the HEPA unit, was escaping under the HEPA unit in the gap created by the wheels. A simple addition of tape and plastic eliminated this path, and no further migration of source aerosol was measured or observed. Smoke tests, such as the one shown in Figure 5, were also helpful in conducting qualitative evaluations to visualize a configuration's ability to quickly capture and remove airborne contaminants.

Particle Control Results

There were 3 key items of interest when the feasibility of the zone-within-zone isolation configurations was assessed: (1) ability to contain the source aerosol within the inner isolation zone(s); (2) ability to prevent source contaminant crossover between patient isolation zones in the 2-patient configuration; and (3) ability to maintain a lower concentration of source aerosol at the health care worker position relative to that surrounding the immediate patient position.

A graph from one of the trial configurations is shown in Figure 6. The disparity in particle counts observed at patient bed 1, the provider position, and the remaining measurement locations produces poor resolution at the lower particle counts. Figure 7 is a reduced-scale version of the same graph to allow better resolution of the particle counts measured outside patient 1's inner isolation zone. In evaluation of the ability of a tested scenario to contain the source aerosol within the inner isolation zone, the particle counts logged by the outer zone aerosol monitors were examined for concentration increases within the 1- to 2-µm band corresponding to the released source aerosol. If all of the outer zone monitors reported steady or decreasing concentrations, the inner zone was considered to have contained the generated source aerosol. In the 2-bed configuration trials, the potential migration of source

Figure 5.
Photograph showing a qualitative smoke test used to verify the airflow path across patient head position and toward the HEPA filtration unit's inlet.

aerosol between patient zones was evaluated by observing concentration trends within the patient 2 isolation zone. Preventing such contaminant crossover could be extremely important if the 2 patients have only a suspect diagnosis, such as with patients recently admitted into a hospital ED. Last, the metric used to determine the relative ability of a tested scenario to reduce the risk of airborne exposure to the health care worker was the mean particle count (within 1- to 2-µm range) observed at the health care worker position divided by that observed near the source patient (monitoring position at center of bed). This value is identified as the "worker/patient exposure ratio." Although the metric is useful in evaluating the different scenarios and in making comparisons between them, there is insufficient evidence to extrapolate this metric to a quantitative exposure reduction in an actual environment.

A summary of the results from the 7 evaluated trial scenarios is shown in the Table. The first trial scenario, a 2-patient configuration with the curtain entrance gap closed, was the worst performing trial among both configurations. However, the knowledge gained by this test run aided the success of subsequent trials. After establishing the desired curtain gap and sealing the gap discovered under the HEPA unit, the aerosol count data for trials 2 through 7 revealed continuous reductions in aerosol counts for those monitors located outside the inner zone, despite the activation of the nebulizer and source generation. Counts outside the enclosures were indistinguishable from background levels present at the beginning of the experiments, indicating that the source aerosol was being successfully contained, captured, and filtered within the inner isolation zone. After trials 1 and 2 revealed slight increases in aerosol concentration within the patient 2 isolation zone, the vertical partition was added to the inlet-side of the HEPA unit, thus isolating the 2 inner isolation zones and eliminating this potential path of contaminant crossover.

The worker-patient exposure ratio shown in the Table reveals mean respirable particle counts at the health care worker position ranging from 30% to 87% lower than those observed at the patient position. Even trials 1 and 2, which were operating under less-than-ideal circumstances, provided a protective benefit to the worker position. The most protective trial among all tested configurations was the 2-patient configuration evaluated during trial 3. Trials 4 and 6 among the single-patient configurations also look promising. There were increased variability and diminished protective effect in trials 5 and 7 when the supply air diffusers were opened within the inner isolation zone, which is believed to be caused by the competing air currents increasing turbulent mixing within the inner isolation zone and disrupting the flow path into the HEPA unit. In practice, supply diffusers within the inner isolation zones should probably remain closed, thus relying on tempered transfer air from the outer zone to meet thermal comfort requirements.

The clinical significance of the observed reductions in provider position particle concentration will depend on what pathogen is being controlled and what other pro-

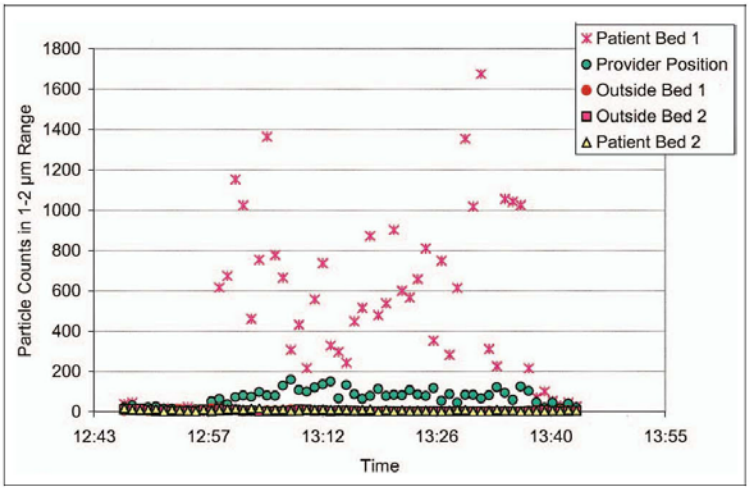


Figure 6.
Graph of data results for trial 3, a 2-patient configuration (patient 1 was the source patient) with the HEPA unit divided vertically at the inlet to prevent crossover between patient areas. Note: the red circles are hidden behind the yellow trianges.

tective precautions are used by the provider. In particular, the proper selection, correct fit, and appropriate use of protective devices such as N95, N99, or N100 respirators, as well as provider care to avoid placing oneself in the path of contaminated air movement, will be critical adjuncts to enclosure ventilation in minimizing provider risk. The key characteristic of the observed reductions is the controlled movement of the particles away from the patient and provider and toward the HEPA unit. This controlled movement allows providers to minimize their exposure by positioning themselves away from the airflow path. Standard isolation rooms do not share this feature because room air is mixed to dilute contaminants rather than being directed in a single flow direction for removal. Furthermore, contaminant removal by directed airflow is virtually immediate, whereas removal by dilution takes place during a period determined by the room volume and ventilation rate.

Costs

The cost of the HEPA filtration unit used in this work was US$2,195, largely because of its heavy-gauge steel construction. However, HEPA units of equivalent filtration capacity are available at significantly lower (and higher) cost, depending on their construction and any additional features such as activated carbon sorption beds for volatile organic chemical removal and ultraviolet biocidal lamps for airstream or filter surface disinfection. The cost of expendable materials used in constructing the enclosures, which included plastic sheeting and packaging tape available in any home improvement store, was well under US$100; however, expendable materials could cost somewhat more in applications requiring larger-scale or more complex construction.

CONCLUSIONS

The current research sought to assess the feasibility of using affordable, off-the-shelf equipment and supplies in combination with a zone-within-zone isolation approach to quickly establish airborne infection isolation for 1 or more patients. As a feasibility study, there were multiple scenarios evaluated, with each scenario receiving insufficient scrutiny to develop rigorous performance predictions. Future research will seek to identify uniform implementation recommendations capable of generating optimum predictable results in a variety of physical environments. In the absence of an emergency scenario, the investigated isolation approach should not be considered an acceptable replacement for engineered airborne infection isolation rooms. However, under extraordinary circumstances where the quantity of engineered airborne infection isolation rooms is insufficient to meet surge demand for patient isolation, hospital facilities could quickly deploy portable filtration equipment in combination with zone-within-zone patient isolation configurations.

Hospitals seeking to use these techniques should preferably obtain the necessary equipment and supplies well in advance of their potential implementation. Identifying rooms for potential conversion, preconstructing the isolation zone boundaries (curtains), and qualitatively testing the configurations with visible smoke will all increase the readiness level of the facility. After testing and

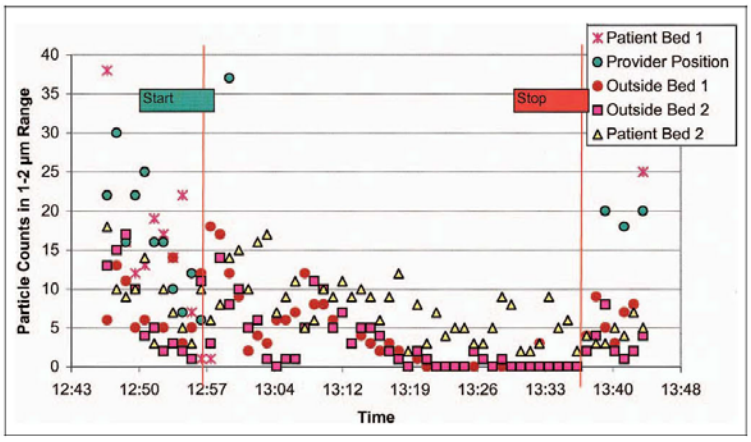


Figure 7.
Reduced-scale graph of trial 3 data in Figure 6 allows better resolution of particle counts recorded at patient bed 2 (the nonsource patient) and locations outside the inner isolation zones. The start line represents the starting point of aerosol generation; the stop line represents the deactivation point of the aerosol generator.

disassembly, reassembly instructions should be generated and stored with the labeled components for future emergency use. During an actual emergency implementation, an initial quantitative leakage and filter performance test of the HEPA filter unit should be conducted using methodologies consistent with those in the CDC Guidelines for Preventing the Transmission of *Mycobacterium tuberculosis* in Health-Care Facilities.[7] In addition, initial and periodic qualitative testing using visible smoke or equivalent should be conducted to verify capture and containment within the inner isolation zone.

The expedient isolation alternative appears to offer fast, affordable, and effective patient isolation during unique circumstances in which engineered isolation rooms are unavailable. The best-performing designs showed no measurable source migration out of the inner isolation zone and mean respirable particle counts up to 87% lower at the health care worker position(s) than those observed directly near the source patient location. The zone-within-zone patient isolation approach also offers a greater protective benefit to nonprovider hospital workers, visitors, and other patients over approaches that rely solely on isolating entire wards, floors, or designated facilities. Such "big-area" approaches invite a wide contaminant distribution that increases the potential for airborne and surface contact exposures to all who enter. In contrast, the inner isolation zones in the zone-within-zone approach use a much higher ventilation rate while containing contaminant distribution within a much smaller area, thereby reducing the potential for airborne or surface contact. The

Table.
Data summary from 7 evaluated trials of 2-patient and single-patient isolation zones created using portable HEPA filtration equipment and common hardware supplies.

Trial No.	Supply/Exhaust (Open or Sealed)	Source Contained Within Inner Zone?	Source Migration Between Patients?	Worker or Patient Exposure Ratio (95% CI)*	Comments
2-patient configuration					
1	Sealed/sealed	N	Y	0.59 (0.45–0.76)	Curtain entrance closed, leak found under HEPA unit, no HEPA inlet partition
2	Sealed/sealed	Y	Y	0.67 (0.44–1.06)	Curtain entrance gap maintained at 10 in (25 cm), no HEPA inlet partition
3	Sealed/sealed	Y	N	0.13 (0.10–0.18)	Curtain entrance gap maintained at 10 in (25 cm), HEPA inlet partition added
Single-patient configuration					
4	Sealed/sealed	Y	NA	0.29 (0.19–0.46)	Increased airflow: curtain entrance gap increased to 12 in (30 cm)
5	Open/open	Y	NA	0.55 (0.37–0.86)	HVAC supply reduces incoming air, curtain entrance gap maintained at 10 in (25 cm)
6	Sealed/open	Y	NA	0.37 (0.28–0.48)	Room HVAC supply located outside of isolation zone was open
7	Open/open	Y	NA	0.70 (0.55–0.92)	Curtain gap maintained at 10 in

Y, Yes; **N,** no; **CI,** confidence interval; **NA,** not applicable.
*This ratio is the mean particle count (within range of 1 to 2 μm) observed at the health care worker position divided by that observed near the source patient. It represents the relative ability of a tested scenario to reduce the risk of airborne exposure to the health care worker.

evaluated expedient designs took fewer than 3 person-hours to construct at a total cost (including US$2,195 for the HEPA unit) of less than US$2,300. Because many hospitals already own high-flow-rate, HEPA-filtered, "negative-air" exhaust systems that they use for dust control during renovation work, the expedient isolation cost could be reduced to perhaps US$50 to US$100 per isolation area because only the plastic sheeting and other expendable materials would be needed. The 3-hour assembly time for the prototype was likely much longer than would be required to erect a preplanned enclosure for which the design was identified and evaluated ahead of time and with which the assemblers were familiar. To minimize construction time, the assembly training and practice could be incorporated into the facility's emergency operations preparation activities.

Recommendations for Follow-up Work

This study was designed as a preliminary assessment of the utility of expedient isolation enclosures for control of airborne pathogens. As such, it has several limitations that should be considered in interpreting the results. First, the study was limited to a discrete set of enclosure designs evaluated in a single facility, whereas actual work environments will undoubtedly require variations to accommodate specific patient care situations and health care facility engineering characteristics. Additional work is needed to refine design options that integrate the enclosure systems with the facility HVAC systems to ensure pathogen control while maintaining patient comfort, without interfering with HVAC operation in other areas of the facility. Second, the measurements were performed without an actual patient in place and undergoing normal care so that the influence of factors such as patient movement, positioning, breathing, and coughing, as well as care provider movements on system effectiveness, remains to be evaluated. Finally, actual pathogenic bioaerosols were not used in the work; however, this should not be considered a limitation because the determining factor in particle movement and filtration efficiency is particle aerodynamic size. Because the viability and pathogenicity of biologic aerosols are negatively affected by environmental conditions, including temperature, humidity, and oxygen toxicity,[13,14] use of inanimate surrogates actually represents a conservative evaluation of system effectiveness.

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Appendix B

Data Processing Steps and Statistical Results from SAS Proc Mixed Model for Aerosol Spectrometer Data

Data Processing Steps

For each study, 26 observations were kept for each block “x” location, “y” trial combination groups. The first five observations were used as background data. Observations 6–11 were transitional data and were not used. Observations 12–26 were used to construct end results for analysis.

Step-by-step calculations were as follows:

1. Calculated the mean of the first five observations to get a background mean (BG_mean)
2. Disregarded observations 6–11
3. Subtracted “BG_mean” from each of the remaining 15 observations (12–26)
4. Assigned “0” to any negative result from step 3
5. Added 0.03 to each value and took the natural log of each result
6. Calculated the mean of the 15 results from step 5
7. Used the value from 6 as the representative value for analysis

SAS PROX MIXED (SAS Version 9.13)—Statistical Analysis and Model Output Reports

Column Header Key
Condition = test condition
Loc = sample location within hospital room
n = number of blocks
gmean = geometric mean
gmeanx_1 = geometric mean reduction ratio for condition "x" relative to condition "1" = (gmean1-gmeanx)/gmean1; × = 2,3
Label ID: loc × con y = sample location "x," test condition "y"
redu_lim = lower 90% confidence limit on the gmean reduction ratio

I. VETERAN'S ADMINISTRATION MEDICAL CENTER (VAMC), OKLAHOMA CITY, OK

Ventilated Headboard Configuration

Condition	Loc	n	gmean
1	A	6	144.281
1	B	6	123.354
1	C	6	5227.949
1	D	6	117.263
1	E	6	151.878
3	A	6	1.899
3	B	6	0.420
3	C	6	0.792
3	D	6	0.616
3	E	6	0.447
2	A	6	0.574
2	B	6	0.465
2	C	6	2.136
2	D	6	0.363
2	E	6	0.574

Loc	n	gmean3_1	gmean2_1
A	6	0.987	0.996
B	6	0.997	0.996
C	6	1.000	1.000
D	6	0.995	0.997
E	6	0.997	0.996

VAMC Ventilated Headboard Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.6399	0.7830	13.2	7.20	<.0001	0.98580
loc b con 3	5.6937	0.7830	13.2	7.27	<.0001	0.98655
loc c con 3	7.9153	0.7830	13.2	10.11	<.0001	0.99854
loc d con 3	5.8913	0.7830	13.2	7.52	<.0001	0.98896
loc e con 3	5.6902	0.7830	13.2	7.27	<.0001	0.98650
loc a con 2	4.2157	0.6116	58	6.89	<.0001	0.95897
loc b con 2	5.5669	0.6116	58	9.10	<.0001	0.98938
loc c con 2	8.6800	0.6116	58	14.19	<.0001	0.99953
loc d con 2	5.1338	0.6116	58	8.39	<.0001	0.98362
loc e con 2	5.7145	0.6116	58	9.34	<.0001	0.99083

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.6399	0.7830	13.2	7.20	<.0001	0.97885
loc b con 3	5.6937	0.7830	13.2	7.27	<.0001	0.97996
loc c con 3	7.9153	0.7830	13.2	10.11	<.0001	0.99783
loc d con 3	5.8913	0.7830	13.2	7.52	<.0001	0.98355
loc e con 3	5.6902	0.7830	13.2	7.27	<.0001	0.97989
loc a con 2	4.2157	0.6116	58	6.89	<.0001	0.94664
loc b con 2	5.5669	0.6116	58	9.10	<.0001	0.98618
loc c con 2	8.6800	0.6116	58	14.19	<.0001	0.99939
loc d con 2	5.1338	0.6116	58	8.39	<.0001	0.97870
loc e con 2	5.7145	0.6116	58	9.34	<.0001	0.98808

Zone-Within-Zone Configuration

Condition	Loc	n	gmean
1	A	6	84.271
1	B	6	129.611
1	D	6	147.024
1	F	6	50.863
1	G	6	49.503
1	H	6	51.695
2	A	5	0.138
2	B	6	112.250
2	D	6	259.801
2	F	6	0.055
2	G	6	0.357
2	H	6	0.682
3	A	6	0.123
3	B	5	108.469
3	D	6	264.705
3	F	6	0.060
3	G	6	0.137
3	H	6	0.143

Loc	n	gmean2_1	gmean3_1
A	6	0.998	0.999
B	6	0.134	0.163
D	6	-0.767	-0.800
F	6	0.999	0.999
G	6	0.993	0.997
H	6	0.987	0.997

VAMC Zone-Within-Zone Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.6451	0.5491	57	10.28	<.0001	0.99115
loc b con 3	-0.7019	0.5676	57	-1.24	0.2213	-4.21204
loc f con 3	5.8577	0.5491	57	10.67	<.0001	0.99284
loc g con 3	5.0002	0.5491	57	9.11	<.0001	0.98313
loc h con 3	5.4948	0.4898	57	11.22	<.0001	0.99068
loc a con 2	5.9060	0.5676	57	10.41	<.0001	0.99297
loc b con 2	-0.4745	0.5491	57	-0.86	0.3911	-3.02516
loc f con 2	6.2091	0.5491	57	11.31	<.0001	0.99496
loc g con 2	4.3141	0.5491	57	7.86	<.0001	0.96649
loc h con 2	3.8853	0.4898	57	7.93	<.0001	0.95341

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.6451	0.5491	57	10.28	<.0001	0.98879
loc b con 3	-0.7019	0.5676	57	-1.24	0.2213	-5.65200
loc f con 3	5.8577	0.5491	57	10.67	<.0001	0.99094
loc g con 3	5.0002	0.5491	57	9.11	<.0001	0.97864
loc h con 3	5.4948	0.4898	57	11.22	<.0001	0.98850
loc a con 2	5.9060	0.5676	57	10.41	<.0001	0.99102
loc b con 2	-0.4745	0.5491	57	-0.86	0.3911	-4.09648
loc f con 2	6.2091	0.5491	57	11.31	<.0001	0.99362
loc g con 2	4.3141	0.5491	57	7.86	<.0001	0.95758
loc h con 2	3.8853	0.4898	57	7.93	<.0001	0.94249

II. St JOSEPH MEMORIAL HOSPITAL (SJMH), LARNED, KS

Ventilated Headboard Configuration

Condition	Loc	n	gmean
1	A	6	27.797
1	B	5	57.346
1	C	6	45.044
1	D	6	28.412
1	E	5	27.066
2	A	6	0.064
2	B	5	0.130
2	C	6	0.073
2	D	6	0.115
2	E	5	0.073
3	A	6	0.072
3	B	5	0.087
3	C	6	0.129
3	D	6	0.083
3	E	5	0.063

Loc	n	gmean2_1	gmean3_1
A	6	0.998	0.997
B	5	0.998	0.998
C	6	0.998	0.997
D	6	0.996	0.997
E	5	0.997	0.998

SJMH Ventilated Headboard Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.8584	0.2389	27.8	24.52	<.0001	0.99571
loc b con 3	6.3426	0.2648	28.7	23.96	<.0001	0.99724
loc c con 3	5.7571	0.2389	27.8	24.10	<.0001	0.99525
loc d con 3	5.7376	0.2389	27.8	24.02	<.0001	0.99516
loc e con 3	5.9416	0.2648	28.7	22.44	<.0001	0.99588
loc a con 2	6.0055	0.2347	16.9	25.59	<.0001	0.99629
loc b con 2	6.0242	0.2601	17.7	23.16	<.0001	0.99620
loc c con 2	6.3451	0.2347	16.9	27.04	<.0001	0.99736
loc d con 2	5.4353	0.2347	16.9	23.16	<.0001	0.99344
loc e con 2	5.8499	0.2601	17.7	22.49	<.0001	0.99548

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.8584	0.2389	27.8	24.52	<.0001	0.99522
loc b con 3	6.3426	0.2648	28.7	23.96	<.0001	0.99689
loc c con 3	5.7571	0.2389	27.8	24.10	<.0001	0.99471
loc d con 3	5.7376	0.2389	27.8	24.02	<.0001	0.99461
loc e con 3	5.9416	0.2648	28.7	22.44	<.0001	0.99536
loc a con 2	6.0055	0.2347	16.9	25.59	<.0001	0.99584
loc b con 2	6.0242	0.2601	17.7	23.16	<.0001	0.99569
loc c con 2	6.3451	0.2347	16.9	27.04	<.0001	0.99704
loc d con 2	5.4353	0.2347	16.9	23.16	<.0001	0.99265
loc e con 2	5.8499	0.2601	17.7	22.49	<.0001	0.99487

Zone-Within-Zone Configuration

Condition	Loc	n	gmean
1	A	6	66.672
1	B	6	32.332
1	C	6	167.496
1	D	6	70.540
1	E	6	6.208
1	F	6	14.688
1	G	2	21.676
1	H	5	6.120
2	A	6	50.574
2	B	6	25.727
2	C	6	138.848
2	D	6	53.110
2	E	6	0.098
2	F	6	0.060
2	G	2	0.249
2	H	5	0.082
3	A	6	30.409
3	B	6	11.601
3	C	6	35.039

3	D	6	6.249
3	E	6	0.054
3	F	6	0.059
3	G	2	0.056
3	H	5	0.054

Loc	**n**	**gmean2_1**	**gmean3_1**
A	6	0.241	0.544
B	6	0.204	0.641
C	6	0.171	0.791
D	6	0.247	0.911
E	6	0.984	0.991
F	6	0.996	0.996
G	2	0.988	0.997
H	5	0.987	0.991

SJMH Zone-Within-Zone Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	**Estimate**	**StdErr**	**DF**	**tValue**	**Probt**	**redu_lim**
loc a con 3	0.7851	0.3214	44.8	2.44	0.0186	0.21745
loc d con 3	2.4237	0.3214	44.8	7.54	<.0001	0.84800
loc e con 3	4.7476	0.3214	44.8	14.77	<.0001	0.98512
loc f con 3	5.5128	0.3214	44.8	17.15	<.0001	0.99308
loc g con 3	5.7495	0.5587	47.9	10.29	<.0001	0.99187
loc h con 3	4.8012	0.3520	46.6	13.64	<.0001	0.98516
loc a con 2	0.2763	0.3214	44.8	0.86	0.3945	-0.30150
loc d con 2	0.2838	0.3214	44.8	0.88	0.3819	-0.29180
loc e con 2	4.1443	0.3214	44.8	12.89	<.0001	0.97280
loc f con 2	5.4982	0.3214	44.8	17.11	<.0001	0.99298
loc g con 2	4.5664	0.5587	47.9	8.17	<.0001	0.97346
loc h con 2	4.3207	0.3520	46.6	12.28	<.0001	0.97601

(Simultaneously corrected for lower 5 percent value; 6 comparisons, 90 percent conf-fixed)

Label	**Estimate**	**StdErr**	**DF**	**tValue**	**Probt**	**redu_lim**
loc a con 3	0.7851	0.3214	44.8	2.44	0.0186	0.07623
loc d con 3	2.4237	0.3214	44.8	7.54	<.0001	0.82057
loc e con 3	4.7476	0.3214	44.8	14.77	<.0001	0.98244
loc f con 3	5.5128	0.3214	44.8	17.15	<.0001	0.99183
loc g con 3	5.7495	0.5587	47.9	10.29	<.0001	0.98917
loc h con 3	4.8012	0.3520	46.6	13.64	<.0001	0.98221
loc a con 2	0.2763	0.3214	44.8	0.86	0.3945	-0.53636
loc d con 2	0.2838	0.3214	44.8	0.88	0.3819	-0.52492

loc e con 2	4.1443	0.3214	44.8	12.89	<.0001	0.96789
loc f con 2	5.4982	0.3214	44.8	17.11	<.0001	0.99171
loc g con 2	4.5664	0.5587	47.9	8.17	<.0001	0.96464
loc h con 2	4.3207	0.3520	46.6	12.28	<.0001	0.97124

III. CENTRAL KANSAS MEDICAL CENTER (CKMC), Great Bend, KS

Ventilated Headboard Configuration

Condition	Loc	n	gmean
1	a	6	174.880
1	b	6	290.878
1	c	6	187.034
1	d	6	189.838
1	e	6	170.579
2	a	6	0.235
2	b	6	0.514
2	c	6	6.265
2	d	6	0.692
2	e	6	0.542
3	a	6	0.444
3	b	6	0.554
3	c	6	14.889
3	d	6	1.238
3	e	6	0.753

Loc	n	gmean2_1	gmean3_1
a	6	0.999	0.997
b	6	0.998	0.998
c	6	0.967	0.920
d	6	0.996	0.993
e	6	0.997	0.996

CKMC Ventilated Headboard Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	5.9080	0.5526	39.7	10.69	<.0001	0.99311
loc b con 3	6.1944	0.5526	39.7	11.21	<.0001	0.99482
loc c con 3	2.4619	0.5526	39.7	4.46	<.0001	0.78376
loc d con 3	4.9641	0.5526	39.7	8.98	<.0001	0.98229
loc e con 3	5.3547	0.5526	39.7	9.69	<.0001	0.98802
loc a con 2	6.6701	0.5526	39.7	12.07	<.0001	0.99678
loc b con 2	6.3952	0.5526	39.7	11.57	<.0001	0.99577
loc c con 2	3.4522	0.5526	39.7	6.25	<.0001	0.91967

loc d con 2	5.6702	0.5526	39.7	10.26	<.0001	0.99126
loc e con 2	5.8072	0.5526	39.7	10.51	<.0001	0.99238

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	**Estimate**	**StdErr**	**DF**	**tValue**	**Probt**	**redu_lim**
loc a con 3	5.9080	0.5526	39.7	10.69	<.0001	0.99122
loc b con 3	6.1944	0.5526	39.7	11.21	<.0001	0.99340
loc c con 3	2.4619	0.5526	39.7	4.46	<.0001	0.72436
loc d con 3	4.9641	0.5526	39.7	8.98	<.0001	0.97742
loc e con 3	5.3547	0.5526	39.7	9.69	<.0001	0.98472
loc a con 2	6.6701	0.5526	39.7	12.07	<.0001	0.99590
loc b con 2	6.3952	0.5526	39.7	11.57	<.0001	0.99460
loc c con 2	3.4522	0.5526	39.7	6.25	<.0001	0.89761
loc d con 2	5.6702	0.5526	39.7	10.26	<.0001	0.98886
loc e con 2	5.8072	0.5526	39.7	10.51	<.0001	0.99028

Zone-Within-Zone Configuration

Condition	**loc**	**n**	**gmean**
1	a	6	91.555
1	b	6	337.570
1	c	6	1982.278
1	d	6	350.396
1	e	6	367.167
1	f	6	150.827
1	g	6	167.788
1	h	6	80.863
2	a	6	0.196
2	b	6	0.831
2	c	6	474.407
2	d	6	25.198
2	e	6	749.690
2	f	6	0.215
2	g	6	0.214
2	h	6	0.115
3	a	6	0.617
3	b	6	3.998
3	c	6	0.634
3	d	6	2.296
3	e	6	563.492
3	f	6	0.263
3	g	6	0.127
3	h	6	0.308

Loc	**n**	**gmean2_1**	**gmean3_1**
a	6	0.998	0.993
b	6	0.998	0.988

c	6	0.761	1.000
d	6	0.928	0.993
e	6	-1.042	-0.535
f	6	0.999	0.998
g	6	0.999	0.999
h	6	0.999	0.996

CKMC Zone-Within-Zone Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	**Estimate**	**StdErr**	**DF**	**tValue**	**Probt**	**redu_lim**
loc a con 3	4.9839	0.4015	20.4	12.41	<.0001	0.98632
loc b con 3	4.4206	0.4015	20.4	11.01	<.0001	0.97598
loc f con 3	6.3354	0.4015	20.4	15.78	<.0001	0.99646
loc g con 3	7.1728	0.4015	20.4	17.87	<.0001	0.99847
loc h con 3	5.5541	0.4015	20.4	13.83	<.0001	0.99227
loc a con 2	6.0724	0.4636	28	13.10	<.0001	0.99493
loc b con 2	5.9328	0.4636	28	12.80	<.0001	0.99417
loc f con 2	6.4782	0.4636	28	13.97	<.0001	0.99662
loc g con 2	6.5894	0.4636	28	14.21	<.0001	0.99697
loc h con 2	6.4832	0.4636	28	13.99	<.0001	0.99664

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	**Estimate**	**StdErr**	**DF**	**tValue**	**Probt**	**redu_lim**
loc a con 3	4.9839	0.4015	20.4	12.41	<.0001	0.98348
loc b con 3	4.4206	0.4015	20.4	11.01	<.0001	0.97099
loc f con 3	6.3354	0.4015	20.4	15.78	<.0001	0.99572
loc g con 3	7.1728	0.4015	20.4	17.87	<.0001	0.99815
loc h con 3	5.5541	0.4015	20.4	13.83	<.0001	0.99066
loc a con 2	6.0724	0.4636	28	13.10	<.0001	0.99374
loc b con 2	5.9328	0.4636	28	12.80	<.0001	0.99280
loc f con 2	6.4782	0.4636	28	13.97	<.0001	0.99583
loc g con 2	6.5894	0.4636	28	14.21	<.0001	0.99627
loc h con 2	6.4832	0.4636	28	13.99	<.0001	0.99585

IV. INTEGRIS BAPTIST MEDICAL CENTER (IBMC), OKLAHOMA CITY, OK

Ventilated Headboard Configuration

Condition	Loc	n	gmean
1	A	6	171.155
1	B	6	159.886
1	C	6	1794.371
1	D	6	125.161
1	E	6	105.024
2	A	6	0.407
2	B	6	0.123
2	C	6	0.172
2	D	6	0.299
2	E	6	0.140
3	A	6	0.351
3	B	6	0.308
3	C	6	0.199
3	D	6	0.257
3	E	6	0.336

Loc	n	gmean2_1	gmean3_1
A	6	0.998	0.998
B	6	0.999	0.998
C	6	1.000	1.000
D	6	0.998	0.998
E	6	0.999	0.997

IBMC Ventilated Headboard Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	6.1345	0.5337	28	11.49	<.0001	0.99463
loc b con 3	6.1972	0.5337	28	11.61	<.0001	0.99495
loc c con 3	9.0514	0.5337	28	16.96	<.0001	0.99971
loc d con 3	6.1357	0.5337	28	11.50	<.0001	0.99464
loc e con 3	5.6913	0.5337	28	10.66	<.0001	0.99163
loc a con 2	5.9412	0.6234	25.6	9.53	<.0001	0.99238
loc b con 2	7.0706	0.6234	25.6	11.34	<.0001	0.99754
loc c con 2	9.1526	0.6234	25.6	14.68	<.0001	0.99969
loc d con 2	5.9351	0.6234	25.6	9.52	<.0001	0.99234
loc e con 2	6.5188	0.6234	25.6	10.46	<.0001	0.99572

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	6.1345	0.5337	28	11.49	<.0001	0.99316
loc b con 3	6.1972	0.5337	28	11.61	<.0001	0.99358
loc c con 3	9.0514	0.5337	28	16.96	<.0001	0.99963
loc d con 3	6.1357	0.5337	28	11.50	<.0001	0.99317
loc e con 3	5.6913	0.5337	28	10.66	<.0001	0.98935
loc a con 2	5.9412	0.6234	25.6	9.53	<.0001	0.98987
loc b con 2	7.0706	0.6234	25.6	11.34	<.0001	0.99673
loc c con 2	9.1526	0.6234	25.6	14.68	<.0001	0.99959
loc d con 2	5.9351	0.6234	25.6	9.52	<.0001	0.98981
loc e con 2	6.5188	0.6234	25.6	10.46	<.0001	0.99431

Zone-Within-Zone Configuration

Condition	Loc	n	gmean
1	A	6	203.690
1	B	6	393.965
1	C	6	2432.382
1	D	6	192.665
1	E	6	155.171
1	F	6	38.713
1	G	6	48.996
1	H	6	49.719
2	A	6	0.503
2	B	6	1.613
2	C	6	4.066
2	D	6	0.221
2	E	6	0.371
2	F	6	0.211
2	G	6	0.114
2	H	6	0.094
3	A	6	0.375
3	B	6	0.459
3	C	6	1.246
3	D	6	0.309
3	E	6	0.243
3	F	6	0.139
3	G	6	0.156
3	H	6	0.176

Loc	n	gmean2_1	gmean3_1
A	6	0.998	0.998
B	6	0.996	0.999
C	6	0.998	0.999
D	6	0.999	0.998
E	6	0.998	0.998
F	6	0.995	0.996
G	6	0.998	0.997
H	6	0.998	0.996

IBMC Zone-Within-Zone Model Results, based on mean of 15 log-transformed, BG-corrected, and baseline-shifted particle count values for each block, trial, and sample position. Date treated as fixed factor.

(Individually corrected for lower 5 percent value)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	6.2087	0.7288	17.2	8.52	<.0001	0.99286
loc d con 3	6.3471	0.7288	17.2	8.71	<.0001	0.99378
loc e con 3	6.3683	0.7288	17.2	8.74	<.0001	0.99391
loc f con 3	5.5395	0.7288	17.2	7.60	<.0001	0.98605
loc g con 3	5.6582	0.7288	17.2	7.76	<.0001	0.98761
loc h con 3	5.5531	0.7288	17.2	7.62	<.0001	0.98624
loc a con 2	5.9026	0.6770	13.1	8.72	<.0001	0.99094
loc d con 2	6.6702	0.6770	13.1	9.85	<.0001	0.99580
loc e con 2	5.9360	0.6770	13.1	8.77	<.0001	0.99124
loc f con 2	5.1130	0.6770	13.1	7.55	<.0001	0.98005
loc g con 2	5.9628	0.6770	13.1	8.81	<.0001	0.99147
loc h con 2	6.1738	0.6770	13.1	9.12	<.0001	0.99310

(Simultaneously corrected for lower 5 percent value; 5 comparisons, 90 percent conf-fixed)

Label	Estimate	StdErr	DF	tValue	Probt	redu_lim
loc a con 3	6.2087	0.7288	17.2	8.52	<.0001	0.98914
loc d con 3	6.3471	0.7288	17.2	8.71	<.0001	0.99054
loc e con 3	6.3683	0.7288	17.2	8.74	<.0001	0.99074
loc f con 3	5.5395	0.7288	17.2	7.60	<.0001	0.97879
loc g con 3	5.6582	0.7288	17.2	7.76	<.0001	0.98116
loc h con 3	5.5531	0.7288	17.2	7.62	<.0001	0.97908
loc a con 2	5.9026	0.6770	13.1	8.72	<.0001	0.98633
loc d con 2	6.6702	0.6770	13.1	9.85	<.0001	0.99366
loc e con 2	5.9360	0.6770	13.1	8.77	<.0001	0.98678
loc f con 2	5.1130	0.6770	13.1	7.55	<.0001	0.96990
loc g con 2	5.9628	0.6770	13.1	8.81	<.0001	0.98713
loc h con 2	6.1738	0.6770	13.1	9.12	<.0001	0.98958

Appendix C

Industrial Hygiene Sampling Optical Counting Lab Results

Location Codes

VA = VAMC, Oklahoma City, OK

GB = CKMC, Great Bend, KS

L = SJMH, Larned, KS

B = IBMC, Oklahoma City, OK

Notes

1. Pump flow rates were 1.5 Lpm at all locations except CKMC, where the flow rate was 2 Lpm.
2. Reported dosing concentration is not a true airborne concentration. Instead, it is the particle count on the filter, divided by the product of the dosing minutes and the pump flow rate.

Industrial Hygiene/Optical Counting Data

	Location Codes:												
	VAMC = VA Medical Center, Oklahoma City, OK							SJMH = ST Joseph Memorial Hospital, Larned, KS					
	CKMC = Central KS Medical Center, Great Bend, KS							IBMC = Integris Baptist Medical Center, Oklahoma, City, OK					
Lab #	**Location**	**#Beds**	**Filter #**	**Block**	**Run**	**Pos**	**Raw Count**	**Date**	**Total Vol**	**Dosing Minutes**	**Condition**	**Count**	**Dosing Conc.**
KM325	VAMC	1	145	5	a	A	1	15-Aug-06	91.5	25	3	1	0.03
KM326	VAMC	1	146	5	a	B	2	15-Aug-06	91.5	25	3	2	0.05
KM327	VAMC	1	147	5	a	D	1	15-Aug-06	91.5	25	3	1	0.03
KM328	VAMC	1	148	5	a	E	1	15-Aug-06	91.5	25	3	1	0.03
KM329	VAMC	1	149	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM330	VAMC	1	150	5	b	A	1	15-Aug-06	91.5	25	2	1	0.03
KM331	VAMC	1	151	5	b	B	1	15-Aug-06	91.5	25	2	1	0.03
KM332	VAMC	1	152	5	b	D	0	15-Aug-06	91.5	25	2	0	0.00
KM333	VAMC	1	153	5	b	E	0	15-Aug-06	91.5	25	2	0	0.00
KM334	VAMC	1	154	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM335	VAMC	1	155	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM336	VAMC	1	156	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM337	VAMC	1	157	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM338	VAMC	1	158	5	c	A	4472	15-Aug-06	108	25	1	4472	119.25
KM339	VAMC	1	159	5	c	B	4378	15-Aug-06	108	25	1	4378	116.75
KM340	VAMC	1	160	5	c	D	4397	15-Aug-06	108	25	1	4397	117.25
KM341	VAMC	1	161	5	c	E	5043	15-Aug-06	108	25	1	5043	134.48
KM342	VAMC	1	162	6	a	A	1	15-Aug-06	90	25	2	1	0.03
KM343	VAMC	1	163	6	a	B	2	15-Aug-06	90	25	2	2	0.05
KM344	VAMC	1	164	6	a	D	0	15-Aug-06	90	25	2	0	0.00
KM345	VAMC	1	165	6	a	E	2	15-Aug-06	90	25	2	2	0.05
KM346	VAMC	1	166	6	b	A	0	15-Aug-06	97.5	25	3	0	0.00
KM347	VAMC	1	167	6	b	B	4	15-Aug-06	97.5	25	3	4	0.11
KM348	VAMC	1	168	6	b	D	6	15-Aug-06	97.5	25	3	6	0.16
KM349	VAMC	1	169	6	b	E	0	15-Aug-06	97.5	25	3	0	0.00
KM350	VAMC	1	170	6	c	A	3411	15-Aug-06	108	25	1	3411	90.96
KM351	VAMC	1	171	6	c	B	3366	15-Aug-06	108	25	1	3366	89.76

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM352	VAMC	1	172	6	c	D	3509	15-Aug-06	108	25	1	3509	93.57
KM353	VAMC	1	173	6	c	E	3872	15-Aug-06	108	25	1	3872	103.25
KM354	VAMC	1	174	7	a	A	2	16-Aug-06	96	25	3	2	0.05
KM355	VAMC	1	175	7	a	B	1	16-Aug-06	96	25	3	1	0.03
KM356	VAMC	1	176	7	a	D	0	16-Aug-06	96	25	3	0	0.00
KM357	VAMC	1	177	7	a	E	0	16-Aug-06	96	25	3	0	0.00
KM358	VAMC	1	178	7	b	A	4495	16-Aug-06	108	25	1	4495	119.87
KM359	VAMC	1	179	7	b	B	4182	16-Aug-06	108	25	1	4182	111.52
KM360	VAMC	1	180	7	b	D	4864	16-Aug-06	108	25	1	4864	129.71
KM361	VAMC	1	181	7	b	E	4880	16-Aug-06	108	25	1	4880	130.13
KM362	VAMC	1	182	7	c	A	3	16-Aug-06	88.5	25	2	3	0.08
KM363	VAMC	1	183	7	c	B	26	16-Aug-06	88.5	25	2	26	0.69
KM364	VAMC	1	184	7	c	D	5	16-Aug-06	88.5	25	2	5	0.13
KM365	VAMC	1	185	7	c	E	7	16-Aug-06	88.5	25	2	7	0.19
KM366	VAMC	1	186	8	a	A	5419	16-Aug-06	120	25	1	5419	144.51
KM367	VAMC	1	187	8	a	B	4293	16-Aug-06	120	25	1	4293	114.48
KM368	VAMC	1	188	8	a	D	4691	16-Aug-06	120	25	1	4691	125.09
KM369	VAMC	1	189	8	a	E	4737	16-Aug-06	120	25	1	4737	126.32
KM370	VAMC	1	190	8	b	A	7	16-Aug-06	82.5	25	2	7	0.19
KM371	VAMC	1	191	8	b	B	3	16-Aug-06	82.5	25	2	3	0.08
KM372	VAMC	1	192	8	b	D	10	16-Aug-06	82.5	25	2	10	0.27
KM373	VAMC	1	193	8	b	E	7	16-Aug-06	82.5	25	2	7	0.19
KM374	VAMC	1	194	fb		fb	0	16-Aug-06		fb	fb	0	fb
KM375	VAMC	1	195	fb		fb	1	16-Aug-06		fb	fb	1	fb
KM376	VAMC	1	196	fb		fb	0	16-Aug-06		fb	fb	0	fb
KM377	VAMC	1	197	fb		fb	2	16-Aug-06		fb	fb	2	fb
KM378	VAMC	1	198	fb		fb	2	16-Aug-06		fb	fb	2	fb
KM379	VAMC	1	199	8	c	A	5	16-Aug-06	82.5	25	3	5	0.13
KM380	VAMC	1	200	8	c	B	3	16-Aug-06	82.5	25	3	3	0.08
KM381	VAMC	1	201	8	c	D	5	16-Aug-06	82.5	25	3	5	0.13
KM382	VAMC	1	202	8	c	E	3	16-Aug-06	82.5	25	3	3	0.08

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM383	VAMC	1	203	9	a	A	4	16-Aug-06	82.5	25	2	4	0.11
KM384	VAMC	1	204	9	a	B	2	16-Aug-06	82.5	25	2	2	0.05
KM385	VAMC	1	205	9	a	D	2	16-Aug-06	82.5	25	2	2	0.05
KM386	VAMC	1	206	9	a	E	3	16-Aug-06	82.5	25	2	3	0.08
KM387	VAMC	1	207	9	b	A	3826	16-Aug-06	108	25	1	3826	102.03
KM388	VAMC	1	208	9	b	B	2706	16-Aug-06	108	25	1	2706	72.16
KM389	VAMC	1	209	9	b	D	3764	16-Aug-06	108	25	1	3764	100.37
KM390	VAMC	1	210	9	b	E	4926	16-Aug-06	108	25	1	4926	131.36
KM391	VAMC	1	211	9	c	A	1	16-Aug-06	82.5	25	3	1	0.03
KM392	VAMC	1	212	9	c	B	3	16-Aug-06	82.5	25	3	3	0.08
KM393	VAMC	1	213	9	c	D	4	16-Aug-06	82.5	25	3	4	0.11
KM394	VAMC	1	214	9	c	E	4	16-Aug-06	82.5	25	3	4	0.11
KM395	VAMC	1	215	10	a	A	4900	17-Aug-06	121.5	25	1	4900	130.67
KM396	VAMC	1	216	10	a	B	3650	17-Aug-06	121.5	25	1	3650	97.33
KM397	VAMC	1	217	10	a	D	4436	17-Aug-06	121.5	25	1	4436	118.29
KM398	VAMC	1	218	10	a	E	4391	17-Aug-06	121.5	25	1	4391	117.09
KM399	VAMC	1	219	10	b	A	0	17-Aug-06	82.5	25	3	0	0.00
KM400	VAMC	1	220	10	b	B	2	17-Aug-06	82.5	25	3	2	0.05
KM401	VAMC	1	221	10	b	D	9	17-Aug-06	82.5	25	3	9	0.24
KM402	VAMC	1	222	10	b	E	5	17-Aug-06	82.5	25	3	5	0.13
KM403	VAMC	1	223	10	c	A	1	17-Aug-06	82.5	25	2	1	0.03
KM404	VAMC	1	224	10	c	B	5	17-Aug-06	82.5	25	2	5	0.13
KM405	VAMC	1	225	10	c	D	0	17-Aug-06	82.5	25	2	0	0.00
KM406	VAMC	1	226	10	c	E	2	17-Aug-06	82.5	25	2	2	0.05
KM407	VAMC	1	227	fb		fb	0	17-Aug-06		fb	fb	0	fb
KM408	VAMC	1	228	fb		fb	0	17-Aug-06		fb	fb	0	fb
KM409	VAMC	1	229	fb		fb	0	17-Aug-06		fb	fb	0	fb
33	CKMC	1	1 Aa	1	a	A	56	16-Aug-05	118	27	3	56	1.04
21	CKMC	1	1 Ba	1	a	B	39	16-Aug-05	118	27	3	39	0.72
11	CKMC	1	1 Ca	1	a	C	551	16-Aug-05	118	27	3	551	10.20
30	CKMC	1	1 Da	1	a	D	48	16-Aug-05	118	27	3	48	0.89

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
7	CKMC	1	1 Ea	1	a	E	36	16-Aug-05	118	27	3	36	0.67
10	CKMC	1	1 Ab	1	b	A	7165	16-Aug-05	124	25	1	7165	143.30
8	CKMC	1	1 Bb	1	b	B	9741	16-Aug-05	124	25	1	9741	194.82
9	CKMC	1	1 Cb	1	b	C	1655	16-Aug-05	124	25	1	1655	33.10
38	CKMC	1	1 Db	1	b	D	7773	16-Aug-05	124	25	1	7773	155.46
23	CKMC	1	1 Eb	1	b	E	6718	16-Aug-05	124	25	1	6718	134.36
20	CKMC	1	1 Ac	1	c	A	37	16-Aug-05	110	25	2	37	0.74
44	CKMC	1	1 Bc	1	c	B	45	16-Aug-05	110	25	2	45	0.90
28	CKMC	1	1 Cc	1	c	C	278	16-Aug-05	110	25	2	278	5.56
22	CKMC	1	1 Dc	1	c	D	74	16-Aug-05	110	25	2	74	1.48
6	CKMC	1	1 Ec	1	c	E	66	16-Aug-05	110	25	2	66	1.32
40	CKMC	1	2 Aa	2	a	A	10799	16-Aug-05	128	25	1	10799	215.98
46	CKMC	1	2 Ba	2	a	B	16795	16-Aug-05	128	25	1	16795	335.90
35	CKMC	1	2 Ca	2	a	C	10361	16-Aug-05	128	25	1	10361	207.22
47	CKMC	1	2 Da	2	a	D	11146	16-Aug-05	128	25	1	11146	222.92
1	CKMC	1	2 Ea	2	a	E	2073	16-Aug-05	128	25	1	2073	41.46
296	CKMC	1	2 Ab	2	b	A	100	16-Aug-05	112	25	3	100	2.00
27	CKMC	1	2 Bb	2	b	B	43	16-Aug-05	112	25	3	43	0.86
34	CKMC	1	2 Cb	2	b	C	421	16-Aug-05	112	25	3	421	8.42
18	CKMC	1	2 Db	2	b	D	106	16-Aug-05	112	25	3	106	2.12
45	CKMC	1	2 Eb	2	b	E	0	16-Aug-05	***	Pump no start		0	error
24	CKMC	1	2 Ac	2	c	A	61	16-Aug-05	112	25	2	61	1.22
16	CKMC	1	2 Bc	2	c	B	78	16-Aug-05	112	25	2	78	1.56
43	CKMC	1	2 Cc	2	c	C	224	16-Aug-05	112	25	2	224	4.48
41	CKMC	1	2 Dc	2	c	D	31	16-Aug-05	112	25	2	31	0.62
49	CKMC	1	2 Ec	2	c	E	57	16-Aug-05	112	25	2	57	1.14
17	CKMC	1	3 Aa	3	a	A	118	17-Aug-05	116	27	2	118	2.19
4	CKMC	1	3 Ea	3	a	E	133	17-Aug-05	116	27	2	133	2.46
12	CKMC	1	3 Ab	3	b	A	136	17-Aug-05	114	26	3	136	2.62
14	CKMC	1	3 Eb	3	b	E	7	17-Aug-05	114	26	3	7	0.13
42	CKMC	1	3 Ac	3	c	A	8755	17-Aug-05	150	26	1	8755	168.37

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
13	CKMC	1	3 Ec	3	c	E	8736	17-Aug-05	150	26	1	8736	168.00
29	CKMC	1	4 Aa	4	a	A	8259	17-Aug-05	124	25	1	8259	165.18
37	CKMC	1	4 Ea	4	a	E	3111	17-Aug-05	124	25	1	3111	62.22
19	CKMC	1	4 Ab	4	b	A	135	17-Aug-05	100	25	2	135	2.70
36	CKMC	1	4 Eb	4	b	E	136	17-Aug-05	100	25	2	136	2.72
25	CKMC	1	4 Ec	4	c	E	130	17-Aug-05	110	25	3	130	2.60
26	CKMC	1	4 Ac	4	c	E	126	17-Aug-05	110	25	3	126	2.52
15	CKMC	1	5 Ea	5	a	E	142	17-Aug-05	118	25	2	142	2.84
39	CKMC	1	5 Eb	5	b	E	10283	17-Aug-05	124	26	1	10283	197.75
2	CKMC	1	5 Ec	5	c	E	113	17-Aug-05	112	25	3	113	2.26
3	CKMC	1	fb	fb	fb	FB	0	17-Aug-05			fb	0	
32	CKMC	1	fb	fb	fb	FB	0	17-Aug-05			fb	0	
48	CKMC	1	fb	fb	fb	FB	1	17-Aug-05			fb	1	
141	SJMH	1	1	1	a	I	5	14-Dec-05	93	25	3	5	0.13
111	SJMH	1	2	1	a	E	130	14-Dec-05	93	25	3	130	3.47
121	SJMH	1	3	1	a	D	129	14-Dec-05	93	25	3	129	3.44
131	SJMH	1	4	1	a	B	141	14-Dec-05	93	25	3	141	3.76
101	SJMH	1	5	1	a	A	1	14-Dec-05	93	25	3	1	0.03
120	SJMH	1	6	1	b	I	1	14-Dec-05	91.5	26	2	1	0.03
140	SJMH	1	7	1	b	E	96	14-Dec-05	91.5	26	2	96	2.46
130	SJMH	1	8	1	b	A	51	14-Dec-05	91.5	26	2	51	1.31
100	SJMH	1	9	1	b	D	80	14-Dec-05	91.5	26	2	80	2.05
110	SJMH	1	10	1	b	B	89	14-Dec-05	91.5	26	2	89	2.28
122	SJMH	1	11	1	c	B	8572	14-Dec-05	103.5	25	1	8572	228.59
102	SJMH	1	12	1	c	I	58	14-Dec-05	103.5	25	1	58	1.55
112	SJMH	1	13	1	c	D	4087	14-Dec-05	103.5	25	1	4087	108.99
132	SJMH	1	14	1	c	E	4753	14-Dec-05	103.5	25	1	4753	126.75
143	SJMH	1	15	1	c	A	4446	14-Dec-05	103.5	25	1	4446	118.56
129	SJMH	1	16	2	a	I	5	15-Dec-05	102	26	2	5	0.13
109	SJMH	1	17	2	a	E	195	15-Dec-05	102	26	2	195	5.00
99	SJMH	1	18	2	a	D	227	15-Dec-05	102	26	2	227	5.82

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
139	SJMH	1	19	2	a	B	243	15-Dec-05	102	26	2	243	6.23
119	SJMH	1	20	2	a	A	191	15-Dec-05	102	26	2	191	4.90
142	SJMH	1	21	fb	fb	FB	0	15-Dec-05				0	fb
133	SJMH	1	22	fb	fb	FB	1	15-Dec-05				1	fb
123	SJMH	1	23	fb	fb	FB	0	15-Dec-05				0	fb
104	SJMH	1	24	2	b	I	150	15-Dec-05	114	25	1	150	4.00
113	SJMH	1	25	2	b	E	6313	15-Dec-05	117	25	1	6313	168.35
114	SJMH	1	26	2	b	D	5948	15-Dec-05	117	25	1	5948	158.61
124	SJMH	1	27	2	b	B	13376	15-Dec-05	117	25	1	13376	356.69
103	SJMH	1	28	2	b	A	6372	15-Dec-05	117	25	1	6372	169.92
135	SJMH	1	29	2	c	I	17	15-Dec-05	93	26	3	17	0.44
125	SJMH	1	30	2	c	E	50	15-Dec-05	94.5	26	3	50	1.28
145	SJMH	1	31	2	c	D	47	15-Dec-05	94.5	26	3	47	1.21
105	SJMH	1	32	2	c	B	47	15-Dec-05	94.5	26	3	47	1.21
115	SJMH	1	33	2	c	A	38	15-Dec-05	94.5	26	3	38	0.97
134	SJMH	1	34	3	a	I	164	15-Dec-05	100.5	25	1	164	4.37
126	SJMH	1	35	3	a	E	6685	15-Dec-05	106.5	25	1	6685	178.27
136	SJMH	1	36	3	a	D	6937	15-Dec-05	106.5	25	1	6937	184.99
146	SJMH	1	37	3	a	B	14788	15-Dec-05	106.5	25	1	14788	394.35
144	SJMH	1	38	3	a	A	6104	15-Dec-05	106.5	25	1	6104	162.77
106	SJMH	1	39	3	b	I	12	15-Dec-05	88.5	26	3	12	0.31
116	SJMH	1	40	3	b	E	99	15-Dec-05	90	26	3	99	2.54
127	SJMH	1	41	3	b	D	94	15-Dec-05	90	26	3	94	2.41
118	SJMH	1	42	3	b	B	55	15-Dec-05	90	26	3	55	1.41
107	SJMH	1	43	3	b	A	75	15-Dec-05	90	26	3	75	1.92
137	SJMH	1	44	3	c	I	3	15-Dec-05	94.5	25.5	2	3	0.08
148	SJMH	1	45	3	c	E	39	15-Dec-05	94.5	25.5	2	39	1.02
138	SJMH	1	46	3	c	D	24	15-Dec-05	96	25.5	2	24	0.63
147	SJMH	1	47	3	c	B	43	15-Dec-05	96	25.5	2	43	1.12
128	SJMH	1	48	3	c	A	18	15-Dec-05	96	25.5	2	18	0.47
117	SJMH	1	49	fb	fb	FB	0	15-Dec-05				0	fb

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
108	SJMH	1	50	fb	fb	FB	0	15-Dec-05				0	fb
197	SJMH	1	51	4	a	I	8	16-Dec-05	88.5	26	3	8	0.21
207	SJMH	1	52	4	a	E	44	16-Dec-05	93	26	3	44	1.13
217	SJMH	1	53	4	a	D	68	16-Dec-05	93	26	3	68	1.74
227	SJMH	1	54	4	a	B	66	16-Dec-05	93	26	3	66	1.69
237	SJMH	1	55	4	a	A	49	16-Dec-05	93	26	3	49	1.26
198	SJMH	1	56	4	b	I	199	16-Dec-05	106.5	25	1	199	5.31
208	SJMH	1	57	4	b	E	5768	16-Dec-05	108	25	1	5768	153.81
218	SJMH	1	58	4	b	D	5210	16-Dec-05	108	25	1	5210	138.93
228	SJMH	1	59	4	b	B	8468	16-Dec-05	108	25	1	8468	225.81
238	SJMH	1	60	4	b	A	5879	16-Dec-05	108	25	1	5879	156.77
199	SJMH	1	61	4	c	I	20	16-Dec-05	93	26	2	20	0.51
209	SJMH	1	62	4	c	E	80	16-Dec-05	93	26	2	80	2.05
219	SJMH	1	63	4	c	D	6	16-Dec-05	16.5	0	2	6	error
NOTE:	219-error	Pump fail before dosing began. Vount value shows flaw in lab protocol OR CROSS-CONTAM FROM HEATER											
229	SJMH	1	64	4	c	B	103	16-Dec-05	94.5	26	2	103	2.64
239	SJMH	1	65	4	c	A	89	16-Dec-05	94.5	26	2	89	2.28
200	SJMH	1	66	5	a	I	3	16-Dec-05	93	25	2	3	0.08
210	SJMH	1	67	5	a	E	72	16-Dec-05	94.5	25	2	72	1.92
220	SJMH	1	68	5	a	D	75	16-Dec-05	94.5	25	2	75	2.00
231	SJMH	1	69	5	a	B	173	16-Dec-05	94.5	25	2	173	4.61
240	SJMH	1	70	5	a	A	45	16-Dec-05	94.5	25	2	45	1.20
241	SJMH	1	71	fb	fb	FB	0	16-Dec-05				0	fb
230	SJMH	1	72	fb	fb	FB	0	16-Dec-05				0	fb
221	SJMH	1	73	5	b	A	36	16-Dec-05	94.5	25	3	36	0.96
211	SJMH	1	74	5	b	B	34	16-Dec-05	96	25	3	34	0.91
201	SJMH	1	75	5	b	D	41	16-Dec-05	96	25	3	41	1.09
242	SJMH	1	76	5	b	E	33	16-Dec-05	94.5	25	3	33	0.88
232	SJMH	1	77	5	b	I	6	16-Dec-05	94.5	25	3	6	0.16
222	SJMH	1	78	5	c*	A	123	16-Dec-05	C* = ERROR - only 1 neb operated			123	error
212	SJMH	1	79	5	c*	B	654	16-Dec-05	rerun block			654	error

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
202	SJMH	1	80	5	c*	D	3274	16-Dec-05				3274	error
243	SJMH	1	81	5	c*	E	5732	16-Dec-05				5732	error
233	SJMH	1	82	5	c*	I	3046	16-Dec-05				3046	error
223	SJMH	1	83	5	c	I	216	16-Dec-05	102	25	1	216	5.76
213	SJMH	1	84	5	c	E	5951	16-Dec-05	105	25	1	5951	158.69
203	SJMH	1	85	5	c	D	6258	16-Dec-05	105	25	1	6258	166.88
244	SJMH	1	86	5	c	B	12299	16-Dec-05	105	25	1	12299	327.97
234	SJMH	1	87	5	c	A	6829	16-Dec-05	105	25	1	6829	182.11
226	SJMH	1	88	6	a	I	334	16-Dec-05	100.5	25	1	334	8.91
214	SJMH	1	89	6	a	E	5461	16-Dec-05	103.5	25	1	5461	145.63
205	SJMH	1	90	6	a	D	6013	16-Dec-05	103.5	25	1	6013	160.35
245	SJMH	1	91	6	a	B	11993	16-Dec-05	103.5	25	1	11993	319.81
235	SJMH	1	92	6	a	A	7032	16-Dec-05	103.5	25	1	7032	187.52
224	SJMH	1	93	6	b	I	44	16-Dec-05	88.5	25	2	44	1.17
215	SJMH	1	94	6	b	E	75	16-Dec-05	90	25	2	75	2.00
204	SJMH	1	95	6	b	D	74	16-Dec-05	90	25	2	74	1.97
246	SJMH	1	96	6	b	B	168	16-Dec-05	90	25	2	168	4.48
236	SJMH	1	97	6	b	A	57	16-Dec-05	90	25	2	57	1.52
225	SJMH	1	98	fb	fb	FB	0	16-Dec-05				0	fb
216	SJMH	1	99	fb	fb	FB	0	16-Dec-05				0	fb
206	SJMH	1	100	fb	fb	FB	0	16-Dec-05				0	fb
70	SJMH	1	101	6	c	A	41	16-Dec-05	85.5	25	3	41	1.09
80	SJMH	1	102	6	c	B	28	16-Dec-05	85.5	25	3	28	0.75
50	SJMH	1	103	6	c	D	36	16-Dec-05	87	25	3	36	0.96
60	SJMH	1	104	6	c	E	25	16-Dec-05	87	25	3	25	0.67
89	SJMH	1	105	6	c	I	5	16-Dec-05	87	25	3	5	0.13
61	SJMH	2	1	1	a	A	1463	17-Dec-05	84	25	3	1463	39.01
91	SJMH	2	2	1	a	B	1676	17-Dec-05	84	25	3	1676	44.69
71	SJMH	2	3	1	a	G	15	17-Dec-05	84	25	3	15	0.40
90	SJMH	2	4	1	a	E	20	17-Dec-05	84	25	3	20	0.53
81	SJMH	2	5	1	a	F	15	17-Dec-05	84	25	3	15	0.40

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
51	SJMH	2	6	1	a	H	14	17-Dec-05	85.5	25	3	14	0.37
82	SJMH	2	7	1	b	A	6003	17-Dec-05	102	25	1	6003	160.08
72	SJMH	2	8	1	b	B	4729	17-Dec-05	102	25	1	4729	126.11
62	SJMH	2	9	1	b	E	909	17-Dec-05	102	25	1	909	24.24
52	SJMH	2	10	1	b	F	1179	17-Dec-05	102	25	1	1179	31.44
53	SJMH	2	11	1	b	G	1041	17-Dec-05	102	25	1	1041	27.76
63	SJMH	2	12	1	b	H	878	17-Dec-05	102	25	1	878	23.41
73	SJMH	2	13	1	c	A	5557	17-Dec-05	85.5	25	2	5557	148.19
83	SJMH	2	14	1	c	B	3803	17-Dec-05	85.5	25	2	3803	101.41
92	SJMH	2	15	1	c	E	109	17-Dec-05	85.5	25	2	109	2.91
54	SJMH	2	16	1	c	F	109	17-Dec-05	85.5	25	2	109	2.91
64	SJMH	2	17	1	c	G	193	17-Dec-05	87	25	2	193	5.15
74	SJMH	2	18	1	c	H	198	17-Dec-05	87	25	2	198	5.28
84	SJMH	2	19	2	a	A	3083	17-Dec-05	85.5	25	3	3083	82.21
93	SJMH	2	20	2	a	B	2247	17-Dec-05	85.5	25	3	2247	59.92
95	SJMH	2	21	2	b	H	175	17-Dec-05	85.5	25	2	175	4.67
55	SJMH	2	22	2	a	E	27	17-Dec-05	84	25	3	27	0.72
65	SJMH	2	23	2	a	F	26	17-Dec-05	85.5	25	3	26	0.69
75	SJMH	2	24	2	a	G	34	17-Dec-05	85.5	25	3	34	0.91
85	SJMH	2	25	2	a	H	31	17-Dec-05	85.5	25	3	31	0.83
add-3	SJMH	2	26	2	b	G	186	17-Dec-05	85.5	25	2	186	4.96
76	SJMH	2	27	2	b	F	122	17-Dec-05	85.5	25	2	122	3.25
67	SJMH	2	28	2	b	E	114	17-Dec-05	85.5	25	2	114	3.04
56	SJMH	2	29	2	b	B	4555	17-Dec-05	85.5	25	2	4555	121.47
94	SJMH	2	30	2	b	A	4592	17-Dec-05	85.5	25	2	4592	122.45
57	SJMH	2	31	2	c	H	1716	17-Dec-05	100.5	25	1	1716	45.76
66	SJMH	2	32	2	c	G	1839	17-Dec-05	100.5	25	1	1839	49.04
77	SJMH	2	33	2	c	F	2355	17-Dec-05	100.5	25	1	2355	62.80
86	SJMH	2	34	2	c	E	1984	17-Dec-05	100.5	25	1	1984	52.91
96	SJMH	2	35	2	c	B	6335	17-Dec-05	100.5	25	1	6335	168.93
58	SJMH	2	36	2	c	A	7518	17-Dec-05	100.5	25	1	7518	200.48

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
68	SJMH	2	37	3	a	H	121	17-Dec-05	82.5	25	2	121	3.23
78	SJMH	2	38	3	a	G	126	17-Dec-05	81	25	2	126	3.36
87	SJMH	2	39	3	a	F	87	17-Dec-05	81	25	2	87	2.32
97	SJMH	2	40	3	a	E	88	17-Dec-05	81	25	2	88	2.35
286	SJMH	2	41	3	a	B	3185	17-Dec-05	82.5	25	2	3185	84.93
277	SJMH	2	42	3	a	A	3205	17-Dec-05	84	25	2	3205	85.47
266	SJMH	2	43	3	b	H	33	17-Dec-05	88.5	25	3	33	0.88
258	SJMH	2	44	3	b	G	31	17-Dec-05	90	25	3	31	0.83
247	SJMH	2	45	3	b	F	30	17-Dec-05	90	25	3	30	0.80
287	SJMH	2	46	3	b	E	41	17-Dec-05	90	25	3	41	1.09
276	SJMH	2	47	3	b	B	2931	17-Dec-05	90	25	3	2931	78.16
267	SJMH	2	48	3	b	A	3736	17-Dec-05	90	25	3	3736	99.63
59	SJMH	2	49	fb		fb	2	17-Dec-05			fb		fb
248	SJMH	2	50	3	c	H	1754	17-Dec-05	111	25	1	1754	46.77
288	SJMH	2	51	3	c	G	1961	17-Dec-05	111	25	1	1961	52.29
278	SJMH	2	52	3	c	F	2442	17-Dec-05	111	25	1	2442	65.12
268	SJMH	2	53	3	c	E	2092	17-Dec-05	111	25	1	2092	55.79
257	SJMH	2	54	3	c	B	7501	17-Dec-05	111	25	1	7501	200.03
249	SJMH	2	55			A	7372	17-Dec-05	111	25	1	7372	196.59
69	SJMH	2	56	fb		fb	0	17-Dec-05					fb
79	SJMH	2	57	fb		fb	0	17-Dec-05					fb
88	SJMH	2	58	fb		fb	0	17-Dec-05					fb
98	SJMH	2	59	fb		fb	0	17-Dec-05					fb
289	SJMH	2	60	fb		fb	0	17-Dec-05					fb
279	SJMH	2	61	fb		fb	0	17-Dec-05					fb
269	SJMH	2	62	fb		fb	0	17-Dec-05					fb
259	SJMH	2	63	fb		fb	0	17-Dec-05					fb
250	SJMH	2	64	fb		fb	0	17-Dec-05					fb
290	SJMH	2	65	4	a	H	1428	18-Dec-05	99	25	1	1428	38.08
280	SJMH	2	66	4	a	G	1360	18-Dec-05	99	25	1	1360	36.27
270	SJMH	2	67	4	a	F	1658	18-Dec-05	97.5	25	1	1658	44.21

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
260	SJMH	2	68	4	a	E	1509	18-Dec-05	97.5	25	1	1509	40.24
251	SJMH	2	69	4	a	B	5027	18-Dec-05	97.5	25	1	5027	134.05
291	SJMH	2	70	4	a	A	6865	18-Dec-05	97.5	25	1	6865	183.07
281	SJMH	2	71	4	b	H	43	18-Dec-05	82.5	25	3	43	1.15
271	SJMH	2	72	4	b	G	52	18-Dec-05	82.5	25	3	52	1.39
261	SJMH	2	73	4	b	F	59	18-Dec-05	82.5	25	3	59	1.57
252	SJMH	2	74	4	b	E	52	18-Dec-05	82.5	25	3	52	1.39
292	SJMH	2	75	4	b	B	3045	18-Dec-05	82.5	25	3	3045	81.20
282	SJMH	2	76	4	b	A	5012	18-Dec-05	82.5	25	3	5012	133.65
272	SJMH	2	77	4	c	H	95	18-Dec-05	82.5	25	2	95	2.53
262	SJMH	2	78	4	c	G	103	18-Dec-05	82.5	25	2	103	2.75
253	SJMH	2	79	4	c	F	70	18-Dec-05	82.5	25	2	70	1.87
293	SJMH	2	80	4	c	E	66	18-Dec-05	82.5	25	2	66	1.76
283	SJMH	2	81	4	c	B	4351	18-Dec-05	82.5	25	2	4351	116.03
273	SJMH	2	82	4	c	A	5880	18-Dec-05	82.5	25	2	5880	156.80
263	SJMH	2	83	5	a	H	1984	18-Dec-05	100.5	25	1	1984	52.91
254	SJMH	2	84	5	a	G	1880	18-Dec-05	99	25	1	1880	50.13
294	SJMH	2	85	5	a	F	2378	18-Dec-05	99	25	1	2378	63.41
284	SJMH	2	86	5	a	E	2051	18-Dec-05	99	25	1	2051	54.69
274	SJMH	2	87	5	a	B	5102	18-Dec-05	100.5	25	1	5102	136.05
264	SJMH	2	88	5	a	A	6224	18-Dec-05	100.5	25	1	6224	165.97
255	SJMH	2	89	5	b	H	199	18-Dec-05	87	25	2	199	5.31
295	SJMH	2	90	5	b	G	161	18-Dec-05	85.5	25	2	161	4.29
285	SJMH	2	91	5	b	F	132	18-Dec-05	85.5	25	2	132	3.52
275	SJMH	2	92	5	b	E	189	18-Dec-05	85.5	25	2	189	5.04
265	SJMH	2	93	5	b	B	4651	18-Dec-05	85.5	25	2	4651	124.03
256	SJMH	2	94	5	b	A	7326	18-Dec-05	85.5	25	2	7326	195.36
149	SJMH	2	95	fb		fb	0	18-Dec-05					fb
159	SJMH	2	96	fb		fb	0	18-Dec-05					fb
168	SJMH	2	97	fb		fb	0	18-Dec-05					fb
178	SJMH	2	98	5	c	H	21	18-Dec-05	84	25	3	21	0.56

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
150	SJMH	2	99	5	c	G	14	18-Dec-05	84	25	3	14	0.37
169	SJMH	2	100	5	c	F	12	18-Dec-05	84	25	3	12	0.32
160	SJMH	2	101	5	c	E	37	18-Dec-05	82.5	25	3	37	0.99
186	SJMH	2	102	5	c	B	4088	18-Dec-05	84	25	3	4088	109.01
177	SJMH	2	103	5	c	A	5053	18-Dec-05	84	25	3	5053	134.75
188	SJMH	2	104	6	a	H	181	18-Dec-05	84	25	2	181	4.83
151	SJMH	2	105	6	a	G	131	18-Dec-05	82.5	25	2	131	3.49
161	SJMH	2	106	6	a	F	139	18-Dec-05	82.5	25	2	139	3.71
170	SJMH	2	107	6	a	E	122	18-Dec-05	82.5	25	2	122	3.25
179	SJMH	2	108	6	a	B	4281	18-Dec-05	82.5	25	2	4281	114.16
189	SJMH	2	109	6	a	A	6618	18-Dec-05	82.5	25	2	6618	176.48
171	SJMH	2	110	6	b	H	2285	18-Dec-05	102	25	1	2285	60.93
152	SJMH	2	111	6	b	G	2200	18-Dec-05	102	25	1	2200	58.67
180	SJMH	2	112	6	b	F	2934	18-Dec-05	102	25	1	2934	78.24
190	SJMH	2	113	6	b	E	2378	18-Dec-05	102	25	1	2378	63.41
162	SJMH	2	114	6	b	B	7037	18-Dec-05	102	25	1	7037	187.65
153	SJMH	2	115	6	b	A	7856	18-Dec-05	102	25	1	7856	209.49
164	SJMH	2	116	6	c	H	37	18-Dec-05	84	25	3	37	0.99
181	SJMH	2	117	6	c	G	17	18-Dec-05	84	25	3	17	0.45
191	SJMH	2	118	6	c	F	16	18-Dec-05	84	25	3	16	0.43
163	SJMH	2	119	6	c	E	43	18-Dec-05	84	25	3	43	1.15
172	SJMH	2	120	6	c	B	3896	18-Dec-05	84	25	3	3896	103.89
154	SJMH	2	121	6	c	A	5015	18-Dec-05	84	25	3	5015	133.73
KM59	IBMC	1	1	1	a	A	0	19-Sep-06	82.5	25	2	0	0.00
KM53	IBMC	1	2	1	a	B	0	19-Sep-06	82.5	25	2	0	0.00
KM61	IBMC	1	3	1	a	D	1	19-Sep-06	82.5	25	2	1	0.03
KM56	IBMC	1	4	1	a	E	0	19-Sep-06	82.5	25	2	0	0.00
KM60	IBMC	1	5	1	b	A	0	19-Sep-06	84	25	3	0	0.00
KM54	IBMC	1	6	1	b	B	1	19-Sep-06	84	25	3	1	0.03
KM52	IBMC	1	7	1	b	D	0	19-Sep-06	84	25	3	0	0.00
KM55	IBMC	1	8	1	b	E	0	19-Sep-06	84	25	3	0	0.00

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM58	IBMC	1	9	1	c	A	6307	19-Sep-06	108	25	1	6307	168.19
KM66	IBMC	1	10	1	c	B	10355	19-Sep-06	108	25	1	10355	276.13
KM57	IBMC	1	11	1	c	D	5958	19-Sep-06	108	25	1	5958	158.88
KM65	IBMC	1	12	1	c	E	5376	19-Sep-06	108	25	1	5376	143.36
KM64	IBMC	1	13	2	a	A	0	20-Sep-06	82.5	25	3	0	0.00
KM63	IBMC	1	14	2	a	B	0	20-Sep-06	82.5	25	3	0	0.00
KM62	IBMC	1	15	2	a	D	0	20-Sep-06	82.5	25	3	0	0.00
KM71	IBMC	1	16	2	a	E	0	20-Sep-06	82.5	25	3	0	0.00
KM70	IBMC	1	17	2	b	A	0	20-Sep-06	82.5	25	2	0	0.00
KM69	IBMC	1	18	2	b	B	0	20-Sep-06	82.5	25	2	0	0.00
KM68	IBMC	1	19	2	b	D	0	20-Sep-06	82.5	25	2	0	0.00
KM67	IBMC	1	20	2	b	E	1	20-Sep-06	82.5	25	2	1	0.03
KM71	IBMC	1	21	fb		fb	0	20-Sep-06	fb	fb	fb	0	fb
KM73	IBMC	1	22	fb		fb	0	20-Sep-06	fb	fb	fb	0	fb
KM74	IBMC	1	23	2	c	A	3692	20-Sep-06	108	25	1	3692	98.45
KM75	IBMC	1	24	2	c	B	5344	20-Sep-06	108	25	1	5344	142.51
KM76	IBMC	1	25	2	c	D	5236	20-Sep-06	108	25	1	5236	139.63
KM92	IBMC	1	25	Err: This is B2-25			4						
KM77	IBMC	1	26	2	c	E	4932	20-Sep-06	108	25	1	4932	131.52
KM78	IBMC	1	27	3	a	A	6206	20-Sep-06	108	25	1	6206	165.49
KM79	IBMC	1	28	3	a	B	5040	20-Sep-06	108	25	1	5040	134.40
KM80	IBMC	1	29	3	a	D	3796	20-Sep-06	108	25	1	3796	101.23
KM81	IBMC	1	30	3	a	E	3676	20-Sep-06	108	25	1	3676	98.03
KM82	IBMC	1	31	3	b	A	1	20-Sep-06	82.5	25	2	1	0.03
KM83	IBMC	1	32	3	b	B	1	20-Sep-06	82.5	25	2	1	0.03
KM84	IBMC	1	33	3	b	D	1	20-Sep-06	82.5	25	2	1	0.03
KM85	IBMC	1	34	3	b	E	1	20-Sep-06	82.5	25	2	1	0.03
KM88	IBMC	1	35	3	c	A	0	20-Sep-06	82.5	25	3	0	0.00
KM89	IBMC	1	36	3	c	B	1	20-Sep-06	82.5	25	3	1	0.03
KM90	IBMC	1	37	3	c	D	0	20-Sep-06	82.5	25	3	0	0.00
KM91	IBMC	1	38	3	c	E	0	20-Sep-06	82.5	25	3	0	0.00

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM86	IBMC	1	39	fb		fb	0	20-Sep-06	fb	fb	fb	0	fb
KM87	IBMC	1	40	fb		fb	0	20-Sep-06	fb	fb	fb	0	fb
KM142	IBMC	1	41	4	a	A	11863	20-Sep-06	109.5	25	1	11863	316.35
KM141	IBMC	1	42	4	a	B	5171	20-Sep-06	109.5	25	1	5171	137.89
KM140	IBMC	1	43	4	a	D	5860	20-Sep-06	109.5	25	1	5860	156.27
KM138	IBMC	1	44	4	a	E	4254	20-Sep-06	109.5	25	1	4254	113.44
KM139	IBMC	1	45	4	b	A	5	20-Sep-06	82.5	25	3	5	0.13
KM143	IBMC	1	46	4	b	B	4	20-Sep-06	82.5	25	3	4	0.11
KM144	IBMC	1	47	4	b	D	4	20-Sep-06	82.5	25	3	4	0.11
KM145	IBMC	1	48	4	b	E	4	20-Sep-06	82.5	25	3	4	0.11
KM146	IBMC	1	49	4	c	A	1	20-Sep-06	82.5	25	2	1	0.03
KM147	IBMC	1	50	4	c	B	1	20-Sep-06	82.5	25	2	1	0.03
KM148	IBMC	1	51	4	c	D	0	20-Sep-06	82.5	25	2	0	0.00
KM149	IBMC	1	52	4	c	E	1	20-Sep-06	82.5	25	2	1	0.03
KM150	IBMC	1	53	5	a	A	2	21-Sep-06	84	25	2	2	0.05
KM151.	IBMC	1	54	5	a	B	0	21-Sep-06	84	25	2	0	0.00
KM152	IBMC	1	55	5	a	D	0	21-Sep-06	84	25	2	0	0.00
KM153	IBMC	1	56	5	a	E	0	21-Sep-06	84	25	2	0	0.00
KM154	IBMC	1	57	5	b	A	3447	21-Sep-06	109.5	25	1	3447	91.92
KM155	IBMC	1	58	5	b	B	2197	21-Sep-06	109.5	25	1	2197	58.59
KM156	IBMC	1	59	5	b	D	3284	21-Sep-06	109.5	25	1	3284	87.57
KM157	IBMC	1	60	5	b	E	3761	21-Sep-06	109.5	25	1	3761	100.29
KM158	IBMC	1	61	fb		fb	0	21-Sep-06	fb	fb	fb	0	fb
KM159	IBMC	1	62	fb		fb	0	21-Sep-06	fb	fb	fb	0	fb
KM160	IBMC	1	63	5	c	A	2	21-Sep-06	82.5	25	3	2	0.05
KM161	IBMC	1	64	5	c	B	1	21-Sep-06	82.5	25	3	1	0.03
KM162	IBMC	1	65	5	c	D	2	21-Sep-06	82.5	25	3	2	0.05
KM163	IBMC	1	66	5	c	E	2	21-Sep-06	82.5	25	3	2	0.05
KM164	IBMC	1	67	6	a	A	2	21-Sep-06	84	25	3	2	0.05
KM165	IBMC	1	68	6	a	B	0	21-Sep-06	84	25	3	0	0.00
KM166	IBMC	1	69	6	a	D	0	21-Sep-06	84	25	3	0	0.00

Industrial Hygiene/Optical Counting Data

	Location Codes:												
	VAMC = VA Medical Center, Oklahoma City, OK								SJMH = ST Joseph Memorial Hospital, Larned, KS				
	CKMC = Central KS Medical Center, Great Bend, KS								IBMC = Integris Baptist Medical Center, Oklahoma, City, OK				
Lab #	**Location**	**#Beds**	**Filter #**	**Block**	**Run**	**Pos**	**Raw Count**	**Date**	**Total Vol**	**Dosing Minutes**	**Condition**	**Count**	**Dosing Conc.**
KM325	VAMC	1	145	5	a	A	1	15-Aug-06	91.5	25	3	1	0.03
KM326	VAMC	1	146	5	a	B	2	15-Aug-06	91.5	25	3	2	0.05
KM327	VAMC	1	147	5	a	D	1	15-Aug-06	91.5	25	3	1	0.03
KM328	VAMC	1	148	5	a	E	1	15-Aug-06	91.5	25	3	1	0.03
KM329	VAMC	1	149	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM330	VAMC	1	150	5	b	A	1	15-Aug-06	91.5	25	2	1	0.03
KM331	VAMC	1	151	5	b	B	1	15-Aug-06	91.5	25	2	1	0.03
KM332	VAMC	1	152	5	b	D	0	15-Aug-06	91.5	25	2	0	0.00
KM333	VAMC	1	153	5	b	E	0	15-Aug-06	91.5	25	2	0	0.00
KM334	VAMC	1	154	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM335	VAMC	1	155	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM336	VAMC	1	156	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM337	VAMC	1	157	fb		fb	0	15-Aug-06		fb	fb	0	fb
KM338	VAMC	1	158	5	c	A	4472	15-Aug-06	108	25	1	4472	119.25
KM339	VAMC	1	159	5	c	B	4378	15-Aug-06	108	25	1	4378	116.75
KM340	VAMC	1	160	5	c	D	4397	15-Aug-06	108	25	1	4397	117.25
KM341	VAMC	1	161	5	c	E	5043	15-Aug-06	108	25	1	5043	134.48
KM342	VAMC	1	162	6	a	A	1	15-Aug-06	90	25	2	1	0.03
KM343	VAMC	1	163	6	a	B	2	15-Aug-06	90	25	2	2	0.05
KM344	VAMC	1	164	6	a	D	0	15-Aug-06	90	25	2	0	0.00
KM345	VAMC	1	165	6	a	E	2	15-Aug-06	90	25	2	2	0.05
KM346	VAMC	1	166	6	b	A	0	15-Aug-06	97.5	25	3	0	0.00
KM347	VAMC	1	167	6	b	B	4	15-Aug-06	97.5	25	3	4	0.11
KM348	VAMC	1	168	6	b	D	6	15-Aug-06	97.5	25	3	6	0.16
KM349	VAMC	1	169	6	b	E	0	15-Aug-06	97.5	25	3	0	0.00
KM350	VAMC	1	170	6	c	A	3411	15-Aug-06	108	25	1	3411	90.96
KM351	VAMC	1	171	6	c	B	3366	15-Aug-06	108	25	1	3366	89.76

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM38	IBMC	2	21	1	c	H	2559	24-Sep-06	108	25	1	2559	68.24
KM37	IBMC	2	22	fb		fb	0	24-Sep-06	fb	fb	fb	0	fb
KM36	IBMC	2	23	fb		fb	0	24-Sep-06	fb	fb	fb	0	fb
KM41	IBMC	2	24	fb		fb	0	24-Sep-06	fb	fb	fb	0	fb
KM92	IBMC	2	25	2	a	A	4	25-Sep-06	82.5	25	3	4	0.11
KM93	IBMC	2	26	2	a	B	13	25-Sep-06	82.5	25	3	13	0.35
KM94	IBMC	2	27	2	a	D	1	25-Sep-06	82.5	25	3	1	0.03
KM95	IBMC	2	28	2	a	E	0	25-Sep-06	82.5	25	3	0	0.00
KM96	IBMC	2	29	2	a	F	0	25-Sep-06	82.5	25	3	0	0.00
KM97	IBMC	2	30	2	a	G	0	25-Sep-06	82.5	25	3	0	0.00
KM98	IBMC	2	31	2	a	H	0	25-Sep-06	82.5	25	3	0	0.00
KM99	IBMC	2	32	2	b	A	19	25-Sep-06	82.5	25	2	19	0.51
KM100	IBMC	2	33	2	b	B	32	25-Sep-06	82.5	25	2	32	0.85
KM101	IBMC	2	34	2	b	D	4	25-Sep-06	82.5	25	2	4	0.11
KM102	IBMC	2	35	2	b	E	0	25-Sep-06	82.5	25	2	0	0.00
KM103	IBMC	2	36	2	b	F	0	25-Sep-06	82.5	25	2	0	0.00
KM104	IBMC	2	37	2	b	G	1	25-Sep-06	82.5	25	2	1	0.03
KM105	IBMC	2	38	2	b	H	0	25-Sep-06	82.5	25	2	0	0.00
KM106	IBMC	2	39	2	c	A	6875	25-Sep-06	108	25	1	6875	183.33
KM107	IBMC	2	40	2	c	B	10178	25-Sep-06	108	25	1	10178	271.41
KM108	IBMC	2	41	2	c	D	4812	25-Sep-06	108	25	1	4812	128.32
KM109	IBMC	2	42	2	c	E	4955	25-Sep-06	108	25	1	4955	132.13
KM110	IBMC	2	43	2	c	F	2073	25-Sep-06	108	25	1	2073	55.28
KM111	IBMC	2	44	2	c	G	2719	25-Sep-06	108	25	1	2719	72.51
KM112	IBMC	2	45	2	c	H	2419	25-Sep-06	108	25	1	2419	64.51
KM113	IBMC	2	46	fb		fb	0	25-Sep-06	fb	fb	fb	0	fb
KM114	IBMC	2	47	fb		fb	0	25-Sep-06	fb	fb	fb	0	fb
KM115	IBMC	2	48	3	a	A	7420	25-Sep-06	108	25	1	7420	197.87
KM116	IBMC	2	49	3	a	B	13898	25-Sep-06	108	25	1	13898	370.61
KM117	IBMC	2	50	3	a	D	7573	25-Sep-06	108	25	1	7573	201.95
KM118	IBMC	2	51	3	a	E	5997	25-Sep-06	108	25	1	5997	159.92

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM119	IBMC	2	52	3	a	F	2582	25-Sep-06	108	25	1	2582	68.85
KM120	IBMC	2	53	3	a	G	2566	25-Sep-06	108	25	1	2566	68.43
KM121	IBMC	2	54	3	a	H	2824	25-Sep-06	108	25	1	2824	75.31
KM122	IBMC	2	55	3	b	A	26	25-Sep-06	82.5	25	2	26	0.69
KM123	IBMC	2	56	3	b	B	41	25-Sep-06	82.5	25	2	41	1.09
KM124	IBMC	2	57	3	b	D	9	25-Sep-06	82.5	25	2	9	0.24
KM125	IBMC	2	58	3	b	E	2	25-Sep-06	82.5	25	2	2	0.05
KM126	IBMC	2	59	3	b	F	0	25-Sep-06	82.5	25	2	0	0.00
KM127	IBMC	2	60	3	b	G	1	25-Sep-06	82.5	25	2	1	0.03
KM128	IBMC	2	61	3	b	H	2	25-Sep-06	82.5	25	2	2	0.05
KM129	IBMC	2	62	3	c	A	5	25-Sep-06	82.5	25	3	5	0.13
KM130	IBMC	2	63	3	c	B	8	25-Sep-06	82.5	25	3	8	0.21
KM131	IBMC	2	64	3	c	D	3	25-Sep-06	82.5	25	3	3	0.08
KM132	IBMC	2	65	3	c	E	0	25-Sep-06	82.5	25	3	0	0.00
KM133	IBMC	2	66	3	c	F	1	25-Sep-06	82.5	25	3	1	0.03
KM134	IBMC	2	67	3	c	G	0	25-Sep-06	82.5	25	3	0	0.00
KM135	IBMC	2	68	3	c	H	1	25-Sep-06	82.5	25	3	1	0.03
KM136	IBMC	2	69	fb		fb	0	25-Sep-06	fb	fb	fb	0	fb
KM137	IBMC	2	70	fb		fb	0	25-Sep-06	fb	fb	fb	0	fb
KM187	IBMC	2	71	4	a	A	12519	25-Sep-06	108	25	1	12519	333.84
KM188	IBMC	2	72	4	a	B	6042	25-Sep-06	108	25	1	6042	161.12
KM189	IBMC	2	73	4	a	D	5798	25-Sep-06	108	25	1	5798	154.61
KM190	IBMC	2	74	4	a	E	4678	25-Sep-06	108	25	1	4678	124.75
KM191	IBMC	2	75	4	a	F	2324	25-Sep-06	108	25	1	2324	61.97
KM192	IBMC	2	76	4	a	G	2265	25-Sep-06	108	25	1	2265	60.40
KM193	IBMC	2	77	4	a	H	1887	25-Sep-06	108	25	1	1887	50.32
KM194	IBMC	2	78	4	b	A	6	25-Sep-06	82.5	25	3	6	0.16
KM195	IBMC	2	79	4	b	B	6	25-Sep-06	82.5	25	3	6	0.16
KM196	IBMC	2	80	4	b	D	3	25-Sep-06	82.5	25	3	3	0.08
KM197	IBMC	2	81	4	b	E	1	25-Sep-06	82.5	25	3	1	0.03
KM198	IBMC	2	82	4	b	F	1	25-Sep-06	82.5	25	3	1	0.03

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM199	IBMC	2	83	4	b	G	2	25-Sep-06	82.5	25	3	2	0.05
KM200	IBMC	2	84	4	b	H	1	25-Sep-06	82.5	25	3	1	0.03
KM201	IBMC	2	85	4	c	A	43	25-Sep-06	82.5	25	2	43	1.15
KM202	IBMC	2	86	4	c	B	39	25-Sep-06	82.5	25	2	39	1.04
KM203	IBMC	2	87	4	c	D	8	25-Sep-06	82.5	25	2	8	0.21
KM204	IBMC	2	88	4	c	E	2	25-Sep-06	82.5	25	2	2	0.05
KM205	IBMC	2	89	4	c	F	2	25-Sep-06	82.5	25	2	2	0.05
KM206	IBMC	2	90	4	c	G	1	25-Sep-06	82.5	25	2	1	0.03
KM207	IBMC	2	91	4	c	H	1	25-Sep-06	82.5	25	2	1	0.03
KM208	IBMC	2	92	fb		fb	0	25-Sep-06	fb	fb	fb	0	fb
KM209	IBMC	2	93	fb		fb	0	25-Sep-06	fb	fb	fb	0	fb
KM210	IBMC	2	94	5	a	A	18	26-Sep-06	82.5	25	2	18	0.48
KM211	IBMC	2	95	5	a	B	12	26-Sep-06	82.5	25	2	12	0.32
KM212	IBMC	2	96	5	a	D	4	26-Sep-06	82.5	25	2	4	0.11
KM213	IBMC	2	97	5	a	E	2	26-Sep-06	82.5	25	2	2	0.05
KM214	IBMC	2	98	5	a	F	0	26-Sep-06	82.5	25	2	0	0.00
KM215	IBMC	2	99	5	a	G	1	26-Sep-06	82.5	25	2	1	0.03
KM216	IBMC	2	100	5	a	H	2	26-Sep-06	82.5	25	2	2	0.05
KM217	IBMC	2	101	5	b	A	6163	26-Sep-06	108	25	1	6163	164.35
KM218	IBMC	2	102	5	b	B	14616	26-Sep-06	108	25	1	14616	389.76
KM219	IBMC	2	103	5	b	D	6741	26-Sep-06	108	25	1	6741	179.76
KM220	IBMC	2	104	5	b	E	4188	26-Sep-06	108	25	1	4188	111.68
KM221	IBMC	2	105	5	b	F	2262	26-Sep-06	108	25	1	2262	60.32
KM222	IBMC	2	106	5	b	G	2086	26-Sep-06	108	25	1	2086	55.63
KM223	IBMC	2	107	5	b	H	2592	26-Sep-06	108	25	1	2592	69.12
KM224	IBMC	2	108	5	c	A	6	26-Sep-06	82.5	25	3	6	0.16
KM225	IBMC	2	109	5	c	B	3	26-Sep-06	82.5	25	3	3	0.08
KM226	IBMC	2	110	5	c	D	2	26-Sep-06	82.5	25	3	2	0.05
KM227	IBMC	2	111	5	c	E	0	26-Sep-06	82.5	25	3	0	0.00
KM228	IBMC	2	112	5	c	F	0	26-Sep-06	82.5	25	3	0	0.00
KM229	IBMC	2	113	5	c	G	0	26-Sep-06	82.5	25	3	0	0.00

Industrial Hygiene/Optical Counting Data

Lab #	Location	#Beds	Filter #	Block	Run	Pos	Raw Count	Date	Total Vol	Dosing Minutes	Condition	Count	Dosing Conc.
KM230	IBMC	2	114	5	c	H	3	26-Sep-06	82.5	25	3	3	0.08
KM231	IBMC	2	115	fb		fb	0	26-Sep-06	fb	fb	fb	0	fb
KM232	IBMC	2	116	fb		fb	0	26-Sep-06	fb	fb	fb	0	fb
KM233	IBMC	2	117	fb		fb	0	26-Sep-06	fb	fb	fb	0	fb
KM234	IBMC	2	118	6	a	A	3	26-Sep-06	82.5	25	3	3	0.08
KM235	IBMC	2	119	6	a	B	1	26-Sep-06	82.5	25	3	1	0.03
KM236	IBMC	2	120	6	a	D	4	26-Sep-06	82.5	25	3	4	0.11
KM237	IBMC	2	121	6	a	E	1	26-Sep-06	82.5	25	3	1	0.03
KM238	IBMC	2	122	6	a	F	0	26-Sep-06	82.5	25	3	0	0.00
KM239	IBMC	2	123	6	a	G	1	26-Sep-06	82.5	25	3	1	0.03
KM240	IBMC	2	124	6	a	H	0	26-Sep-06	82.5	25	3	0	0.00
KM241	IBMC	2	125	6	b	A	4329	26-Sep-06	108	25	1	4329	115.44
KM242	IBMC	2	126	6	b	B	8585	26-Sep-06	108	25	1	8585	228.93
KM243	IBMC	2	127	6	b	D	6222	26-Sep-06	108	25	1	6222	165.92
KM244	IBMC	2	128	6	b	E	4097	26-Sep-06	108	25	1	4097	109.25
KM245	IBMC	2	129	6	b	F	1760	26-Sep-06	108	25	1	1760	46.93
KM246	IBMC	2	130	6	b	G	1645	26-Sep-06	108	25	1	1645	43.87
KM247	IBMC	2	131	6	b	H	2132	26-Sep-06	108	25	1	2132	56.85
KM248	IBMC	2	132	6	c	A	19	26-Sep-06	81	25	2	19	0.51
KM249	IBMC	2	133	6	c	B	12	26-Sep-06	81	25	2	12	0.32
KM250	IBMC	2	134	6	c	D	4	26-Sep-06	81	25	2	4	0.11
KM251	IBMC	2	135	6	c	E	6	26-Sep-06	81	25	2	6	0.16
KM252	IBMC	2	136	6	c	F	0	26-Sep-06	81	25	2	0	0.00
KM253	IBMC	2	137	6	c	G	1	26-Sep-06	81	25	2	1	0.03
KM254	IBMC	2	138	6	c	H	3	26-Sep-06	81	25	2	3	0.08
KM255	IBMC	2	139	fb		fb	1	26-Sep-06	fb	fb	fb	1	fb
KM256	IBMC	2	140	fb		fb	1	26-Sep-06	fb	fb	fb	1	fb
KM257	IBMC	2	141	fb		fb	1	26-Sep-06	fb	fb	fb	1	fb
KM258	IBMC	2	142	fb		fb	1	26-Sep-06	fb	fb	fb	1	fb
KM259	IBMC	2	143	fb		fb	1	26-Sep-06	fb	fb	fb	1	fb

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