# Proceedings of the Workshop on Engineering Controls for Preventing Airborne Infections in Workers in Health Care and Related Facilities

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# AEROSOL CHARACTERIZATION

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## INTRODUCTION

The setting of a national research agenda to investigate, evaluate, and recommend strategies for engineering controls for the prevention of airborne infectious disease transmission to health care and related workers requires consideration of the factors relevant to aerosol characterization. Those factors include aerosol generation, particle sizes and concentrations, organism viability, infectivity and virulence, airflow and climate, and environmental sampling and analysis. The major focus of such planned research stems from the increasing incidence of tuberculosis, particularly the multiple drug resistant (MDR) variety in the general hospital population, the severely immunocompromised, and those in at-risk and confined environments such as prisons, nursing homes, and shelters for the homeless. Many workers are in close contact with individuals having active, undiagnosed, or insufficiently treated tuberculosis. Additionally, such workers are similarly exposed to a variety of pathogenic human viruses, and upon occasion, to other highly infectious disease agents. This report thus focuses on aerosol characterization in an attempt to identify those research needs that can be systematically addressed, and

result in proven, applied engineering approaches to the protection of workers routinely or periodically exposed to airborne infectious disease agents.

## BACKGROUND

In 1991 there were more than 26,000 active tuberculosis (TB) cases in the United States — a 2.3% increase over 1990 and 18.4% over 1985 (Lewis, 1992). This dramatic increase was primarily among the homeless, drug abusers, and those infected with the human immunodeficiency virus (HIV). The immigration of individuals from areas of high incidence is another causative factor (MMWR, 1990). Additionally, individuals who have failed to complete their TB treatment have fostered the development of multiple drug resistant strains of the primary causative agent, *Mycobacterium tuberculosis*. According to the CDC, virtually all new infection in the country today is contracted through the aerosol route from infected patients who are coughing and dispersing infective droplet nuclei into the air (Snider, 1992). Health care and other workers exposed to confined and TB-prevalent populations are very much at risk of infection. In an intensive care unit, 14 of 45 (31%) hospital staff who were exposed to an active, undiagnosed TB case over a five day period, were infected (Catanzaro, 1982), and a prison guard on immunosuppressive therapy contracted a fulminant and fatal case of tuberculosis from HIV infected inmates (MMWR, July 1992). Tuberculosis has been declared an endemic and nosocomial infection in nursing homes (Schlossberg, 1988).

Tuberculosis is a severe, infectious disease, predominantly pulmonary, that is caused by *M. tuberculosis* and *M. africanum* primarily from humans, and *M. bovis* primarily from cattle (Benenson, 1990). Those infected with HIV are also predisposed to infection with other mycobacteria to include *M. avium*, *M. intracellulare*, and *M. scrofulaceum* (Blaser et al., 1986). Tuberculosis occurs when airborne droplet nuclei containing few or even single infectious units may bypass the bronchial mucociliary

apparatus and reach and multiply in the terminal air spaces (Des Prez and Heim, 1992). Infection in the lungs commonly begins in the lower division of the lower lobe, the middle lobe, the lingula, and the anterior portion of the upper lobes; and while in most cases there is a single initial focus, one-fourth or more of cases show multiple foci (Des Prez and Heim, 1992). Bacilli are ingested by alveolar macrophages, continue to multiply, and spread to regional lymph nodes where progressive disease may occur rapidly or after many years. In children and the elderly, the primary focus may become an area of advancing pneumonia (Des Prez and Heim, 1992).

In addition to tuberculosis, health care and related workers remain at risk for contracting other infectious airborne diseases in the indoor environment to include those that are viral (influenza, measles, chickenpox), chlamydial (psittacosis), bacterial (Legionnaire's disease), and fungal (aspergillosis).

## OBJECTIVE

The objective of this paper is to review the current status of infectious aerosol characterization and to identify and prioritize those research needs relative to the application of engineering controls for the prevention of airborne infections in workers in health care and other related facilities. The infectious aerosols of consideration are those that are generated as respirable size particles by both human and environmental sources, and have the capability of remaining viable and airborne for extended periods of time in the indoor environment. This definition precludes those skin and mucus membrane exposures occurring from splashes (rather than true aerosols) of blood or body fluids containing infectious disease agents.

## AEROSOL CHARACTERIZATION

An assessment of airborne infectious entities requires investigation into their generation, as well as their particle sizes, aerodynamic

properties, concentrations, infectivity and virulence, and viability in relation to climate factors (temperature, relative humidity).

## Bioaerosol Generation

### Human Source

Most respiratory infections (mycobacterial, viral) are transmitted by the airborne route from human sources and are due to the inhalation of droplet nuclei. Such droplet nuclei are small (<6 μm) infectious particles of respiratory secretions that are aerosolized by coughing, sneezing, talking, or singing. A cough can generate some 3,000 droplet nuclei, as can talking for five minutes (Des Prez and Heim, 1992). A sneeze can generate as many as 40,000 droplets, which can evaporate to particles in the 0.5-12 μm range (Cox, 1987). The U.S. Centers for Disease Control and Prevention (CDC) states that the number of mycobacteria that are expelled into the air from a person with tuberculosis correlates with a number of factors, to include the presence of cough or other forceful expirational maneuvers, and the willingness or ability of the patient to cover his or her mouth when coughing (MMWR, 1990). Particles larger than droplet nuclei that settle out from the air can potentially be reentrained back into the indoor air following decreased size due to droplet evaporation, in combination with an aerosol generating activity such as making a bed. Aerosol chamber studies have demonstrated the aerial dispersion of *Staphylococcus aureus* from the activity of a colonized operating room technician linked to wound infection in eleven patients (Tanner et al., 1980).

### Environmental Source

Airborne opportunistic infectious disease microorganisms emanating from a variety of environmental sources have long been a concern in regard to nosocomial infection and hospital infection control. Susceptible health care and related workers are also at risk of infection from such agents. While person-to-person transmission has not been documented, Legionnaire's disease has occurred from exposure to aerosols generated from contaminated cooling towers (Dondero et al., 1980; Garbe et al., 1985).

Additionally, the causative agent, *Legionella pneumophila*, has been isolated from aerosols produced by water faucets and shower heads (Bollin et al., 1985), humidifiers and nebulizers (Arnow et al., 1992), and by squeezing manual ventilation bags (Woo et al., 1986). Sources of *Aspergillus* spores in health care facilities have been identified as outdoor construction (Sarubbi et al., 1982), indoor construction and ceiling tile (Streifel, 1988), air conditioners (Wadowsky and Benner, 1987), and contaminated carpet (Hunt, 1987). Other potential environmental sources of *Aspergillus* are components of heating, ventilation, and air-conditioning (HVAC) systems, to include contaminated filters, condensate, cooling coils, air intakes, and porous insulation in air ducts.

## Bioaerosol Size and Aerodynamics

Infectious bioaerosol particles may exist as 1) single bacterial cells or spores, fungal spores, or viruses; 2) aggregates of several cells, spores, or viruses; or 3) as biological material carried by other, non-biological particles (Nevalainen et al., 1993). Microorganisms span wide size ranges. In general, infectious microorganisms will range from 0.3-10 µm for bacterial cells and spores, 2.0-5.0 µm for fungal spores, and 0.02-0.30 µm for viruses. Specific pathogen sizes include 0.3-0.6 X 1-4 µm for *M. tuberculosis* (Wayne and Kubica, 1986); 0.3-0.90 x 2.0-20 µm for *Legionella pneumophila* (Brenner et al., 1984); 2.5-3.0 µm for *Aspergillus fumigatus* spores (Samson and van Reenen-Hoekstra, 1988); and 0.09-0.12 µm for influenza virus (Murphy and Kingsbury, 1990). Most infectious particles generated from human respiratory sources will occur primarily as droplet nuclei, 0.5-5.0 µm diameter (Owen and Ensor, 1992). As droplets are forcefully expelled from the respiratory tract they begin to evaporate and thus change in respect to their mass and aerodynamic diameter. Upon complete evaporation, the particles may be small enough to remain airborne in the indoor air flow. As pointed out almost sixty years ago, the size of droplet nuclei depends on the amount of solid matter contained in the evaporating droplet (Wells, 1934). Microorganisms however are hygroscopic, and so

the relative humidity of an indoor environment can have a dramatic effect on the particle's aerodynamic size, length of time airborne, and viability. The latter is extremely important, as only a viable microorganism can initiate an infectious process. Gravitational, thermal, and electrostatic fields also affect the aerodynamic behavior (Cox, 1987).

## Bioaerosol Infectivity and Virulence

The infectious disease process in an animal host is a function of microorganism concentration (infective dose) and virulence (disease promoting factors) that enable an agent to overcome the normal physical and immunological defenses of the host. For humans, the initiation of some microbial diseases requires only small infective doses, as the agents have affinity for specific tissue, and possess one or more potent virulence factors that render them resistant to inactivation. For example, infection with airborne *Francisella tularensis* (the causative agent of tularemia) is reported to result from a single microorganism, whose virulence is associated with a cellular capsule (Cox, 1987). Only a few cells of *M. tuberculosis*, with its unique and resistant cell wall structure, are required to overcome normal lung clearance and inactivation mechanisms in a susceptible host. Susceptibility increases through chronic exposure and decreased immune function that may result from a variety of natural or self-induced predisposing factors such as aging, crowded living conditions, heavy smoking, poor nutrition, alcoholism, etc. Tuberculosis epidemics can occur among persons congregated in enclosed spaces such as homeless shelters, nursing homes, hospitals, schools, prisons, and office buildings. Infectivity and the need for HVAC engineering controls for TB were demonstrated over thirty years ago. Experiments were conducted that exposed guinea pigs to air vented from a ward where TB patients were receiving drug therapy. Over a two year period, out of an average of 156 guinea pigs exposed continuously to the air from a six bed tuberculosis ward, 71 became infected (Riley et al., 1959).

Viral infectivity and virulence is undoubtedly more readily noticeable to the general public. Each year viral influenza epidemics

sweep the globe, some with greater virulence than others. During major epidemics, influenza hospitalizations for high-risk persons may increase 2-5 fold (MMWR, May 1992), placing health care workers at increased risk of infection. Small infective doses are thought to be responsible due to the rapidity with which the disease spreads throughout a population. Couch et al. (1981) studied natural airborne transmission of respiratory infection with Coxsackie A virus type 21. Using two groups of adult volunteers—one infected with the virus, and the other non-infected and antibody free—separated by a double walled, wire screen four feet wide, transmission of infection was demonstrated on day six, as a wave of infection swept the previously non-infected group. Measles is a highly contagious viral disease that is spread by the airborne route. The infective dose is small, and as few as four doses per minute from an infected individual can initiate an epidemic (Riley, 1980). Additionally, rubella (German measles) and varicella (chicken pox) viruses can be readily spread via aerosols in indoor air.

Airborne fungi, most notably *Aspergillus fumigatus* and other species, are a very serious infectious disease threat to those who are immunocompromised due to immunosuppressive or cytotoxic therapy.

Inherent in the infection process initiated by the inhalation of infectious droplet nuclei is the area of deposition within the respiratory tract. Such deposition is influenced by hygroscopicity, as an increase in the size of inhaled aerosols occurs through moisture take up as they move within the airways. Knight (1973) estimates that a 1.5 μm hygroscopic particle—a common size in coughs and sneezes—will increase to 2.0 μm in diameter when passing through the nose, and to 4.0 μm in the saturated air of the nasopharynx and the lung. He further theorizes that the effect of hygroscopicity and the resultant particle size change will increase retention in the tertiary bronchioles and alveolar ducts, an effect that may be significant for virus aerosols that are highly infectious for that part of the lung.

## Bioaerosol Viability and Climate Factors

When pathogenic microorganisms leave their host and are aerosolized, they are potentially injured during the generation process. Additionally, once airborne they are outside of their natural habitat and, depending upon a variety of environmental factors, are increasingly subject to loss of viability over time. Viability can be defined as the capability of a microorganism to reproduce. Even if a microorganism remains alive yet cannot reproduce, it can be considered non-viable, for it has lost the ability to survive and reestablish a population within a defined environment. Factors influencing the survival of bioaerosols include their suspending medium, as well as temperature, humidity, oxygen sensitivity, and exposure to ultraviolet or electromagnetic radiation. Using a variety of bacteria, Wells (1934 b) generated data that indicated microorganisms could remain viable in the airborne state for periods that permitted their wide dissemination. Once aerosolized in the indoor environment, microorganisms are subject to lethal desiccation, which results from an interplay of organism morphology, physiology, oxygen sensitivity, and suspending medium, with varying levels of humidity and temperature, in addition to air movements, pressure fluctuations, air ions, and other airborne pollutants (Cox, 1987). Thus, the survival potential of any given microbial pathogen when aerosolized is unique to that organism under those specific conditions at that particular point in time. An assessment of environmental factors relative to bacterial and viral survival in aerosols has been reviewed (Mohr, 1991).

### Temperature and Relative Humidity

Temperature and relative humidity are important factors in aerosol survival. The effects of varied relative humidities can be studied only when temperature is controlled. Many laboratory investigations have established, in particular, that the effect of relative humidity on airborne microorganisms is an important but unpredictable factor. Harper (1961) investigated the survival (for

up to 23 hours) of four viruses (vaccinia, influenza A, polio, and Venezuelan equine encephalomyelitis [VEE]) aerosolized at varying temperature and relative humidity (RH) in the dark. He found that, in general, virus survival at each RH was better at lower temperature than at higher temperature. In addition, vaccinia, influenza, and VEE viruses survived better at low RH (17-25%), while polio virus showed greatest survival at high RH (80-81%). Miller and Artenstein (1967) studied the survival of three aerosolized human respiratory viruses (adenoviruses 4 and 7, parainfluenza 3) in static chambers at three relative humidities (20%,50%,80%) and found that the adenoviruses survived better at 80% RH, while the parainfluenza virus survived better at 20% RH. The studies were carried out with aerosols having mass median diameters of about 2.0 μm. Davis et al. (1971) conducted dynamic aerosol studies using adenovirus 12 at 28-30°C and 89%, 51%, and 32% RH, and found that survival increased as RH increased, and that the same relationship was found for the recovery of the virus from the lungs of exposed newborn hamsters. Schaffer et al. (1976) investigated effects of different means of virus propagation (cell cultures, egg cultures) on stability of influenza A virus at mid-range RH (50-80%), and showed varying survival as a factor of method of propagation. More recently, Ijaz and colleagues (1985) looked at survival of airborne human coronavirus 229E at different conditions of temperature (20°C and 6°C) and RH (30%, 50%, 80%), and found that maximum survival of the aerosolized virus was very much temperature dependent at 80% RH.

All of these studies, as well as many others, indicate that the role of the environment on the survival of airborne microorganisms is extremely complex, and that for practical application to the control of airborne infectious agents, research must move from the laboratory test chamber to the actual indoor environment using previously developed standardized techniques and approaches.

## ENVIRONMENTAL SAMPLING AND ANALYSIS

All existing methods of bioaerosol sampling are potentially applicable to the recovery of infectious disease agents from indoor air. Detailed reviews of bioaerosol sampling methodology are available (Cox, 1987; Fradkin, 1987, Chatigny, 1983). Sampling focuses primarily on the recovery of viable microorganisms using methods of impingement, impaction, filtration, centrifugal separation, or electrostatic and thermal precipitation. All bioaerosol samplers will fatally damage some portion of the total microorganisms collected. Such injury may occur through impaction onto culture media, other surfaces, or through sampler wall losses, turbulence in impingement fluid, desiccation on filter media, etc. Organism loss is also related to the rate of flow of air sampled. A filter method may sample at a rate of four liters per minute, while an all-glass impinger samples at a rate of 12.5 l/min, a sieve impactor at 28.3 l/min, a high volume impactor at 180 l/min, and other high volume samplers at hundreds or thousands of liters per minute. All samplers must be calibrated as to flow rate prior to use, and their collection efficiencies as a function of particle size and shape established previously.

Collection efficiencies are typically determined in controlled laboratory studies using particles of known size and shape under controlled conditions. A laboratory study of collection efficiencies of commonly used bioaerosol samplers was recently published (Jensen et al., 1992); and the physical factors affecting the performance of bioaerosol samplers, particularly in regard to the concept of stopping distance, have been intensively addressed (Nevalainen et al., 1992). Comparative sampler performance evaluations have also been conducted under field conditions with natural aerosols (Lundholm, 1982). Recent aerosol research has described the inlet sampling efficiencies of several commercial bioaerosol samplers, as well as the design of a single stage impactor that can be used to study different sampling and analysis variables, such as relative humidity, sampling flow rate, and desiccation time, which affect bioaerosol viability (Willeke et al.,

1993). Such research can be critical in identifying sampling instruments and techniques to recover infectious agents that might be particularly sensitive to collection, and are present only in small numbers in the indoor air, as perhaps *M. tuberculosis*. Efficient aerosol sampling methods and techniques for the collection of *M. tuberculosis* from indoor air have not yet been described. Other airborne mycobacteria have been successfully recovered from the outdoor air however, using impactor samplers with specified, enriched media (Falkinham et al., 1990). A variety of aerosol sampling techniques and analysis procedures have been used for the recovery of human viruses and have been reviewed (Chatigny, 1983; Sorber, 1987). The scope of the problem of sampling for airborne pathogens is exemplified by research results (Gerone et al., 1966) with natural aerosols of Coxsackie A-21 virus. It was found that if individuals harbored $10^4$ $TCID_{50}$ of virus per milliliter of oral secretions, sneezed 100 times in a closed room (70,000 liters), and atomized $5.9 \times 10^{-6}$ ml of secretions with each sneeze, 12,000 liters of air would have to be sampled to recover one $TCID_{50}$ of virus.

Analysis of collected samples is no longer restricted to the collection of bioaerosols for culture for viability. New techniques, as commonly used in the clinical microbiology laboratory now have application to environmental monitoring, particularly when the goal is demonstration of airborne infectious agents. A variety of techniques, such as fluorescent antibody, monoclonal antibody, gene probe, and polymerase chain reaction (PCR) now afford other isolation and identification/confirmation options, particularly as rapid analysis and assessment of the indoor air becomes increasingly more important. While bioaerosol recovery and rapid analysis methods and techniques have been addressed (Morey et al., 1990), much research remains to be done in order to refine and standardize those optimum procedures that will prove effective in regard to the characterization of infectious disease aerosols.

## RESEARCH NEEDS AND RECOMMENDATIONS

Needed bioaerosol research directed toward the development, implementation, and evaluation of effective engineering controls for preventing airborne infections in workers in health care and related facilities requires basic and applied investigation. Research goals include 1) selection and evaluation of appropriate model or surrogate pathogens for each of the major groups of infectious disease microorganisms of concern (e.g., mycobacteria, respiratory viruses); 2) evaluation of existing and experimental sampling methods or techniques for the recovery of selected model microorganisms; 3) on-site evaluation of existing individual or combined engineering controls using selected model microorganisms and recommended aerosol recovery techniques; and, 4) evaluation of experimental engineering controls and/or pathogen detection devices using selected model microorganisms and recommended aerosol recovery techniques.

### Model Microorganism Selection and Evaluation

Regardless of laboratory and aerosol test chamber data indicating the effectiveness of specific engineering controls, such potential applications must be eventually evaluated in actual indoor environments. Such studies in unoccupied buildings would require the aerosolization of one or more suitable model or indicator microorganisms. Such organisms would be required to be non-pathogenic to humans, to be related to the target human pathogen and possess similar aerosol and inactivation kinetics, and to be recoverable from the indoor air. The selection of such organisms would follow the identification from the literature of potential candidates, with subsequent chamber characterization in the aerosolized state, to include assessment of potential recovery techniques. For example, *Mycobacterium phlei* would appear to be a candidate model organism for use in evaluating indoor engineering controls for preventing the airborne transmission of tuberculosis. *M. phlei* is non-pathogenic for humans, is a rapidly growing and pigmented environmental *Mycobacterium*, and has

been found to be ten times more resistant than virulent *M. tuberculosis* bacilli to ultraviolet radiation (Riley et al., 1976). Its generation as an aerosol, perhaps in artificial sputum, would need to be assessed in the laboratory relative to its resultant airborne characterization. Additionally, the appropriate collection medium and bioaerosol sampler(s) would also need to be identified.

Similarly, model viruses and their recovery techniques could be selected for use in evaluating potential engineering controls in indoor environments. Aerosolized murine influenza viruses have been used as an infectious respiratory disease model (Fairchild and Roan, 1972), and poliovirus type 1 and simian rotavirus SA11 have been used to assess germicidal effectiveness of UV light (Sattar et al., 1984). Bacteriophages have long served as excellent models for disinfection studies relative to the inactivation of human viruses in water and wastewater. Research is needed to identify those bacteriophages that might serve as models of infectious human respiratory viruses in indoor air studies aimed at evaluating engineering controls.

## Bioaerosol Sampling Methods Evaluation

The recovery of selected airborne model microorganisms would need to be assessed in the laboratory in order that optimum samplers, sampling times, collection media, and incubation temperatures and times are identified for each model microorganism. Both existing, available, bioaerosol samplers, and experimental bioaerosol samplers should be included.

The most important aspect of this evaluation is the overall objective of the sampling. Unlike sampling indoor air for allergens or sensitizing microorganisms, the goal of recovering real or model human pathogens may be solely to demonstrate their presence or absence, as opposed to accurate quantitation per unit volume of air. Assuming that the goal of engineering controls for airborne human pathogens is to significantly reduce human exposure to them, and the presence of even one of them is unacceptable

following air treatment, then the sampling and recovery research would need to focus on the collection of large and/or high volume samples to demonstrate the presence or absence of collected model organisms in a significantly large volume of indoor air. As indicated in the literature, the successful collection of natural microbial aerosols, because of their low concentrations, requires the sampling of large volumes of air (Cox, 1987). High volume sampling however, normally brings with it a higher potential for injury of microorganisms through the recovery process due to physical injury and/or desiccation from collection in a high flow rate air stream. Large volume (or long-term) sampling for extended time periods at a much lower flow rate also presents problems in regard to maintenance of viability of collected microorganisms over time. Research is needed to devise methods for the continuous sampling of bioaerosols.

## Existing Engineering Controls Evaluation

Selected model microorganisms and sampling methods can be used to evaluate existing environmental engineering controls or combinations of controls for the prevention of transmission of infectious agents in the workplace. Three methods of air quality control are identified: source control, removal control, and dilution control (Woods and Rask, 1988). Source control minimizes contamination within an occupied space, such as a laminar flow bed providing local or source control for a newly diagnosed tuberculosis patient. Removal control utilizes various air cleaning devices to control particulates by either active or passive mechanisms. Active removal involves the use of devices with media filters or electronic air cleaners, such as the use of portable HEPA filtration units in the rooms of TB patients, while passive removal involves mechanisms such as particle settling, ion diffusion charging, thermophoresis, and coalescence (Woods and Rask, 1988). Dilution control involves the reduction of airborne contaminants by the introduction of less contaminated air into the occupied space, and may occur via natural or mechanical ventilation.

Another air quality control that may be used in conjunction with other methods of particulate removal or dilution is ultraviolet (UV) air disinfection. The goal is to inactivate human pathogenic microorganisms in droplet nuclei in the air supplied to occupied spaces harboring potentially susceptible individuals. While it is recognized that different microorganisms vary in their susceptibility to UV, the application of the technology to control airborne TB in health care and other work environments has been shown to be of value and is well described by Riley (1988) and Nardell (1988).

## Experimental Controls/Devices Development and Evaluation

The research and development of experimental bioaerosol engineering control technologies may provide additional means of controlling infectious disease transmission in the indoor environment. For example, basic research on the use of pulsed high electric fields to inactivate microorganisms (Hamilton and Sale, 1967; Mizuno and Hori, 1988; Hayamizu et al., 1989) indicates the need for investigation of such a technique for potential applications to control airborne microbial contamination in air handling systems.

While a variety of in situ optical techniques provide a powerful resource for the measurement of particle size distributions (Rader and O'Hern, 1993), there are none at the present time that can differentiate viable biological particles from non-viable and/or non-biological ones. Dedicated research efforts aimed at the development of real-time devices to detect viable from non-viable/non-biological airborne particulates could in the near future provide for continuous monitoring and thus early warning detection and/or control systems in health care and other related facilities. Such devices would theoretically be designed to use light scattering or other physical means to detect only airborne microorganisms of certain pathogen groups, such as cells of *Mycobacterium*, spores of *Aspergillus*, or perhaps even units of respiratory viruses. Further investigation is needed to demonstrate the feasibility of the concept of light scattering to differentiate viable biological particles from non-viable/non-biological

ones. Basic light scattering studies using an electrodynamic balance have been published (Davis and Periasamy, 1982; Davis and Periasamy, 1985).

## IMPLEMENTATION OF RESEARCH RECOMMENDATIONS

In the context of a national strategy, it is suggested that recommended research, in the area of aerosol characterization relative to engineering controls for preventing airborne infections in workers in health care and related facilities, be implemented with consideration of the following:

- Recognition that both basic and applied bioaerosol research programs are necessary to the achievement of the goal of prevention of airborne infections in specific worker populations.
- Coordination of all relevant federally funded basic and applied bioaerosol research programs to accelerate achievement of defined goals, avoid duplication of efforts, and contain costs.
- Simultaneous initiation of both basic and applied bioaerosol research programs. For example, initial laboratory experimentation leading to the development of a viable particle detector for airborne tubercle bacilli could run concurrently with applied efforts at identification of a model *Mycobacterium* to use to evaluate the effectiveness of existing engineering controls for eliminating the transmission of *M. tuberculosis* in indoor air.
- Minimization of start-up time and related costs through identification of, and cooperation with, individuals and organizations having existing expertise and facilities (e.g.,aerosol chambers, aerosol engineers, microbiology laboratories) necessary to conduct bioaerosol research.
- Cooperation with standard setting organizations having interest and relevance to aerosol characterization

research, for example the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), and the American Society for Testing and Materials (ASTM); as well as professional associations providing technical platforms for the discussion and dissemination of technical research information, such as the American Association for Aerosol Research (AAAR), and the American Industrial Hygiene Association (AIHA).

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