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

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Executive Summary

- **Sampling and testing methods**

  There is need to develop sampling and testing methods which will provide real-time or near real-time determination of contaminant levels. There also is a need to identify a non-pathogenic surrogate for testing and evaluation of control methods.

- **Interdisciplinary communication**

  The feasibility of a health care control technology data base, including control solutions from a wide range of areas should be studied and, if feasible, be developed.

- **Comprehensive control study**

  Control of airborne infectious disease is dependent on the application of a number of control methods and work practices. A control study should be performed in the health care setting to validate the cumulative effect of a comprehensive application of control procedures (e.g., ventilation, isolation, respiratory protection, administrative procedures, etc.).

Philip J. Bierbaum, M.E.
Morton Lippmann, Ph.D., CIH

Co-Chairs

WORKSHOP OPENING — RICHARD A. LEMEN, Ph.D.

Good morning and thank you for coming to this scientific workshop on engineering controls in health care and related facilities. I bring you regards from Dr. J. Donald Millar, the Director of NIOSH, who was called to Washington today to testify before a Senate committee about the extent of occupational disease and injury in this country. As a result he has asked that I deliver his remarks to you at this conference. I am excited to see such a diverse group of scientists and health professionals gathered in one room. Dr. Millar wanted me to especially mention how pleased he was to see Dr. Theodore Eickhoff, from the University of Colorado Health Science Center, participating with us. Dr. Eickhoff and Dr. Millar trace their friendship back to their EIS officer training days when Dr. Eickhoff was one of his mentors. He wanted me to mention that Dr. Eickhoff's illustrious career in infectious disease has been an inspiration to him.

Oliver Wendell Holmes, the 19th century American writer and physician once wrote:

> I find the great thing in this world is not so much where we stand, as in what direction we are moving: To reach the port of heaven, we must sometimes sail with the wind and sometimes against it,—but we must sail, and not drift, nor lie at anchor.

This expresses exactly how I feel about today's conference. I am very encouraged by the direction in which we are moving. Our meeting here today clearly indicates that we have decided to sail. We will sail into the rising surge of infectious disease in health care and related workers by combining all our knowledge into a collective pool of information.

I don't have to tell you that airborne infectious diseases are a very real problem among workers in health care and related facilities.

I think that's all I want to cover as far as the charge for the workshop, and the logistics of how we want to proceed. At this point, I would like to introduce Dr. Morton Lippmann, who is a friend of mine from the industrial hygiene community. He is currently the chair of the NIOSH Board of Scientific Counselors, which provides NIOSH with advice on our research agendas and our scientific approach to our research. He is a professor at the Nelson Institute of Environmental Medicine, New York University Medical Center. I would now like to have him share with you what his visions are about the workshop.

Etiologic Agents in Airborne Nosocomial Infection

A substantial number of viruses, bacteria and fungi are capable of spread via the airborne route in hospitals. The *possibility* of airborne transmission and the *documentation* of airborne transmission are quite different, however, and the problem is complicated by the fact that many, if not most of the pathogens to be discussed are capable of spreading by more than one route. Many common respiratory viral infections, for example, may be spread by large droplets, actually a form of indirect contact, and by droplet nuclei carried in the air. This discussion will be focused, therefore, on pathogens for which there is good evidence of at least some transmission via the airborne route.

Viruses believed to be spread at least in part by the airborne route in hospitals are shown in Table 2. The common respiratory viruses, including rhinoviruses, influenza and parainfluenza viruses, respiratory syncytial virus, and adenoviruses are included in this category. The evidence in support of airborne rather than droplet spread of many of these viruses is often incomplete. There is good epidemiological evidence, however, for airborne transmission of respiratory syncytial virus and adenoviruses in pediatric wards (Chanock, et al., 1961; Gardner, et al., 1973; Hall, 1981). The strongest epidemiological evidence of airborne transmission of influenza comes not from the hospital setting, but rather from a well-documented outbreak that occurred on a commercial aircraft (Moser, et al., 1979). There is also some epidemiological evidence in support of such transmission in hospital wards (Hoffman and Dixon, 1977).

Among the common viral exanthems, the evidence in support of airborne transmission is quite strong with respect to varicella-zoster virus and measles (Valenti, 1992; Ayliffe and Lowbury, 1982). Rubella may also be spread by the airborne route, but the evidence is not as compelling.

tuberculosis could be transmitted via the air in hospitals (Ehrenkranz and Kicklighter, 1972). Tuberculosis is, in many ways, the prototype airborne infection, since there is evidence that tubercle bacilli are transmitted more effectively by the airborne route than by any other. Droplet nuclei, owing to their very small size, may be inhaled directly into the smallest subdivisions of the lower respiratory tract, the alveoli themselves. Steps necessary to control this threat will likely be discussed extensively at this workshop.

Group A streptococcal airborne transmission in hospitals is fortunately infrequent, but has occurred. The source has almost invariably been a physician or nurse and spread has been from the nares, pharynx, vagina, or anus (Goldmann, 1992). Meningococcal nosocomial infection has fortunately been rare, but has probably occurred (Cohen, et al., 1979).

In general, enteric gram-negative bacteria are spread only rarely, if at all, via the air, since they are quite susceptible to drying. Other non-enteric gram-negative organisms, however, including *Pseudomonas* and *Acinetobacter*, have been transmitted through the air. Allen and Green reported an outbreak of multidrug-resistant *Acinetobacter anitratus* infections in patients in neurosurgical wards and the intensive care unit of a general hospital (Allen and Green, 1987). Most of the infections involved the respiratory tracts of ventilated patients, but the respiratory equipment could not be implicated as the source of the outbreak. The investigators believed that airborne transmission played a major role in perpetuation of this outbreak, but the proportion of infection caused by airborne spread could not be determined. It is worth noting, however, that this particular organism has been found to be unique among gram-negative bacilli in its relative resistance to drying (Hirai, 1991).

In the last two decades, *Legionella pneumophila* and related species have emerged as significant nosocomial pathogens that may be spread via air. Probably the lack of evidence of person-to-person spread facilitated acceptance of Legionnaire's Disease as an airborne infection. Spread through infectious aerosols has been amply demonstrated; several other epidemics have implicated ventilation systems (LaForce, 1992). Perhaps the most vivid such outbreak occurred in Memphis in the summer of 1978; 44 cases of *L. pneumophila* pneumonia occurred in patients in a particular wing of a hospital (Dondero, et al., 1980). The investigation revealed that the cooling tower for an auxiliary air-conditioning system was contaminated with the organism; normal aerosol drift occurred and was drawn into the air intake of the hospital's ventilation system. This outbreak emphasized again that careful consideration must be given to locating air intakes for ventilation systems.

Other bacteria implicated in spread through ventilation systems have included Clostridia, Nocardia, and perhaps atypical mycobacteria. There have been several recent reports of possible airborne transmission of Nocardia, usually involving high-risk patients in special care units, such as transplant recipients (Houang, et al., 1980; Sahathevan, et al., 1991).

Among the fungi (Table 4), only *Aspergillus* and, to a lesser extent, Zygomyces, have been implicated as major airborne hazards in the hospital setting. Most of these outbreaks have been associated with hospital construction or renovation (Weems, et al., 1987). Airborne aspergillus infections have proven to be a

Table 4.

Fungi that Cause Airborne Nosocomial Infection
Aspergillus
Zygomyces (*Mucor* and others)

particular hazard in special care units in which severely granulocytopenic patients are housed. Bone marrow transplant patients are at particular risk, but the increased risk can be controlled by HEPA filtration and laminar airflow (Sherertz, et al., 1987; Rhame, 1991).

In an extensive review (Ayliffe, 1991), Ayliffe cited an unpublished study carried out in Birmingham, England, in which the postoperative wound infection rate in an unventilated operating suite, during the year preceding installation of a ventilation system, was 8.8%; in the year following installation of a plenum ventilation system with 20 air changes per hour, the infection rate was 12.6%! Furthermore, there was a 50% reduction in airborne bacterial counts after the ventilation system was installed. He cited evidence that most wound infections are acquired in the operating room from the patient's own microbial flora, the balance being acquired mainly from staff present in the OR during surgery. Since air is an important source of infection in infections involving insertion of prostheses of various kinds, the use of ultraclean air and exhaust-ventilated clothing is frequently recommended. The value of this technology in other kinds of surgical procedures, however, is doubtful.

The primacy of people as a source of presumably direct and indirect transmission, as opposed to airborne transmission, of nosocomial pathogens was supported by Maki, et al., who did extensive environmental microbiological sampling of a new university hospital in Madison, Wisconsin before and after it was put into use (Maki, et al., 1982). The attack rate of nosocomial infections in the new hospital was no different from the attack rate in the old hospital, thus suggesting that organisms in the inanimate environment contributed little if at all to endemic nosocomial infections. In interpreting this study, however, we must recall that spread of nosocomial pathogens from people via an airborne route in the hospital setting is well established.

It appears, however, that Brachman was not far off in his 1970 estimate (Brachman, 1971), and a more recent estimate of the relative incidence of airborne infections is about 10% of the whole of endemic nosocomial infection (Schaal, 1991).

Epidemic nosocomial infections must be considered, as well. CDC studies carried out during the early 1970s suggested that

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(1979) for Construction and Equipment of Hospital and Medical Facilities, Public Health Service (PHS). The outdoor air ventilation rates in these publications are presented in air changes per hour (ach). Conversion to cfm per person for the ASHRAE Standard was accomplished using the stated occupancy per 1000 ft^2 of floor space and an unstated estimate of nine feet ceiling height. The earlier PHS publication became the source if the more recent one prescribed no outdoor air rates. Unlike the federal guidelines the ASHRAE Standard does not prescribe total air change rates. The PHS publications call for high efficiency filtration of the air supplied to spaces employed in patient treatment and care, thus recognizing the value of particulate removal and resulting reduced concentration of particulates within the occupied space to the health of both patients and staff.

In 1987 (and recently reaffirmed), the American Institute of Architects (AIA) published guidelines with ventilation rates similar to the PHS Guidelines except for operating rooms. For these rooms both outdoor air and total air changes were reduced from 4 and 20 ach to 3 and 15 ach. The 1991 ASHRAE Applications Handbook recommends both outdoor and total air change rates for hospital spaces extracted from the PHS Minimum Requirements published in 1979. For operating rooms, these sources advocate 5 and 25 ach for outdoor and total air.

It is interesting to note that following World War II, eight ach of 100% outdoor air (no recirculation) was commonly applied for operating room ventilation. This was then increased to 12 ach in 1963 (Gaulin, 1963). In 1969, the outdoor air component was reduced to 5 ach by the Public Health Service (PHS, 1969).

For operating rooms, there can be perceived two changes in ventilation practice over the last half of the century. One, reducing the outdoor air rate. This can be attributed to several factors: improvements and greater reliability of filtration of recirculated air, improvements in anesthesia, scavenger ventilation, and the imperative for energy conservation. An increase in total air circulation was followed by a reduction, as represented by the

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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 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

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

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patient talks, coughs, or sneezes. The time course for the production of this infective particle varies with the type of infectious disease. For acute infections, such as rubella and rubeola, a fairly predictable time period is followed from incubation to pre-clinical infection to acute illness. Production of viral particles in the respiratory tract follows a predictable time course with infectivity decreasing as the disease resolves.

For chronic infections such as tuberculosis, the production of infectious droplet nuclei may follow a more prolonged and much less predictable course with significant differences among patients in the number of organisms expelled into the air over a specific time period. There are several factors which determine the infectiousness of an individual (CDC, 1990). These include clinical factors and behavioral factors.

Patients with laryngeal or pulmonary tuberculosis are usually more infectious than patients with extrapulmonary TB. Among those with pulmonary TB, people with cavitary disease are more infectious (American Thoracic Society, 1983). Although data are limited, people with concomitant HIV infection do not appear to be more infectious than those without HIV infection taking into account other factors (CDC, 1990). Patients who cough also appear to be more infectious, and the ability of the patient to cover their mouth while coughing modifies this risk. Procedures that may induce a cough in an infected person obviously increase the risk of transmission (more on this below).

Treatment factors are also important. Administration of effective therapy to a patient decreases the infectiousness of the patient (Riley, et al., 1962, Rouillon et al., 1976). However, the time course for that reduction in infectiousness varies among patients depending on both personal factors and factors related to the treatment (Noble, 1981). Patients with multiple drug resistant (MDR) tuberculosis appear to be infectious longer after treatment has been started than those without drug resistant infections (Beck-Sague et al., 1992).

method were only available on a research level, valuable information on the relative efficacy of different control procedures could be obtained (e.g., efficacy of different ventilation designs).

More Research Using Current Methods on Identifying Infectious Patients

The current epidemic provides an opportunity for developing better information on the identification of infectious patients using current methodologies. Much of this information will be gained from monitoring the skin test conversion rates of employees in health care facilities and relating this to their exposure to infected patients, use of control procedures, etc. While it is unfortunate that these workers are becoming infected, it is critical that we learn as much as we can from this experience. Much of the recently available data have been derived from epidemics among health care facility employees and/or patients (Beck-Sague et al., 1992, CDC, 1989). In nearly all of these situations, many different aspects of the control programs in those facilities have broken down, making it difficult to isolate the efficacy (or lack thereof) of individual control procedures. We must also monitor conversion rates, etc. in other health care facilities with less pronounced problems. This monitoring must be long term, must carefully document the implementation and use of control procedures, and must follow standardized testing procedures.

Workers in other types of health care facilities or occupations where there may be considerable contact with infectious individuals must also be evaluated. These include a number of health care and related areas which provide service for people at high risk of tuberculosis. Important ones include emergency rooms, home health care, outpatient clinics, drug and alcohol treatment facilities, homeless shelters, and correctional facilities. Others may be noted through our surveillance efforts.

Information from the clinical follow-up of infected patients must also be pursued. For tuberculosis, for example, it would be useful to know how many patients discharged based on current criteria (e.g., three consecutive negative smears, etc.) are still infectious and transmission of tuberculosis to HIV-infected patients and in the occurrence of aspergillosis in patients receiving bone transplants, etc. (CDC, 1990, Rhame, 1991). HIV-infected health care workers also appear to be at greater risk in these settings (CDC, 1990). A better understanding of indicators of susceptibility to these infections would be useful for protecting workers from the airborne transmission of these diseases. Such information could be useful for individuals to make decisions about their personal risk and to take steps to further prevent exposures.

Behavioral Factors

Many of our measures to control the spread of airborne infections will be dependent on patient compliance, particularly for chronic illnesses such as tuberculosis. Ensuring that patients cover their mouths when coughing, wear respirators, remain in isolation rooms, etc. is difficult when these behaviors must be maintained for long periods of time. Many of the infected people have many other personal problems (drug addiction, etc.) and are likely to resist many of these requirements. Efforts are needed to develop and evaluate programs to improve compliance with these efforts.

Special Procedures

Procedures that may induce cough or involve contact with the patient's respiratory tract can increase the risk of airborne disease transmission. Cough induction procedures (sputum induction, aerosolized pentamidine administration, etc.) can be done in enclosed booths. Some of these have systems that filter the air through HEPA filters prior to returning the air to the general room area or exhaust the air outside the room. The efficacy of these units needs to be evaluated. Bronchoscopy and similar pulmonary procedures also pose some risk of airborne disease transmission. Given the potential for very high exposures to infectious droplet nuclei during these procedures, general room ventilation is probably not adequately protective even if increased to very high levels. Local exhaust systems appear to be a good alternative, but

Additional diagnostic and treatment service areas which should be addressed include:

- Outpatient surgery and recovery.
- Clinic or ambulatory care center.
- Endoscopy suite or other components of a short procedure or minor surgery suite.
- 23-hour stay unit for pre- or post-procedural care or monitoring.
- Respiratory therapy.
- Dental operatory and clinic.
- X-ray.

In addition to the specific treatment spaces, waiting areas (Nolan, 1992), toileting facilities and possibly food service should be designed or planned to allow use by infectious patients or those suspected of being infectious. No standards, other than procedural protocols, generally exist for facilities such as these to deal with infectious patients. With the pressure to decrease inpatient utilization and attendant costs, it seems that pressure to develop such facilities will grow.

There are also issues of containment which need to be addressed in areas such as the morgue and autopsy suite (Abrutyn, 1992). The lab itself may need to include P-3 containment facilities (Culliton, 1992).

Psychosocial and Ethical Issues

The accepted means of preventing airborne transmission rely on physical barriers, which by their very nature reduce contact between health care worker and patient. This runs counter to an increasing trend to make the health care setting and interactions more humane. For those patients whose admission is not voluntary, the issues of confinement and separation can be even more severe.

Especially for those whose condition requires long lengths of stay, special consideration needs to be given to their psychosocial needs. In both acute care and intensive care settings, the possibility of isolation psychosis must be considered. Additional means responsible for publishing future editions of the *Guidelines* document. Depending upon the timing of this material's production, an addendum should be considered instead of waiting for a more comprehensive update. Because of the overlap, in many cases, of patient populations, those groups participating in research, public education, etc. programs on AIDS should participate in related TB programs.

Specific educational programs should be sponsored by interested and committed industry groups such as the following:

- American Institute of Architects
- American Hospital Association
- Joint Commission on the Accreditation of Healthcare Organizations
- American Correctional Association

Research participants should include the following:

- American Council of Schools of Architecture — Research Council
- American Hospital Association
- American Institute of Architects
- American National Standards Institute
- American Public Health Association
- American Society of Heating, Refrigerating and Air Conditioning Engineers
- American Society of Hospital Engineers of the AHA
- Centers for Disease Control and Prevention
- Department of Defense
- Department of Health and Human Services
- Department of Housing and Urban Development
- Department of Veterans Affairs
- National Fire Protection Association
- National Institute of Building Sciences
- National Institutes of Health
- National Institute for Occupational Safety and Health (NIOSH)

In his paper entitled "Historical Background," Dr. Richard L. Riley reported on the history of airborne contagion for a conference on that topic sponsored by the New York Academy of Sciences (Riley, 1980). A quick synopsis of the history as described by Riley follows:

- 1862 Pasteur published "Memoir on the Organized Corpuscles that Exist in the Atmosphere."

- 1876 John Tyndall quote:

  "I have spoken of the floating dust of the air, of the means of rendering it visible (the Tyndall beam), and of the perfect immunity from putrefaction which accompanies the contact of germless infusions and moteless air."

- 1910 Charles V. Chapin quote:

  "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 2 or 3 feet, a phenomenon which after all resembles contact infection more than it does aerial infection as ordinarily understood."

- 1931 William F. Wells develops the Wells centrifuge for the examination of bacteria in the air.

- 1934 Wells publishes "On Airborne Infection. Study II: Droplets and Droplet Nuclei."

- 1935 Wells and G.M.Fair publish work on the effect of UV radiation on sterilizing air.

- 1941 Robertson et al. publish work on use of aerosol glycols to sterilize air.

- 1957 & 1962 R.L.Riley et al. demonstrate spread of TB by air in a Baltimore Veterans Hospital.

- 1968 Schulman demonstrates natural airborne transmission of influenza in mice.

- 1970 A single small pox patient in a West German hospital infects 19 others whom he had never seen.

- 1978 E.C.Riley reports on a measle epidemic in an elementary school where the ventilation system is implicated.

Commenting on the development of the technique of air disinfection Riley closes his 1980 historical perspective with:

> "Failure of cooperation between architects, engineers, microbiologists and the people developing the technique of air disinfection has held back progress. The medical profession remains confused and, by and large, has not given its blessing to air disinfection in hospitals."

Indeed, it seems as if the engineering community and the health care community has with rare exceptions worked independently not only on disinfection of air but also on all other aspects of its conditioning and delivery.

Two of the more notable exceptions are The Department of Health and Human Services (DHHS), (including all of its ancestors), and the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc (ASHRAE). DHHS, which has had an intimate involvement since 1947, today has enlisted the services of the American Institute of Architects to continue the evolution and publishing of guidelines for health care facility construction. ASHRAE continues to edit and publish its own design guide in the form of a chapter of the popular ASHRAE handbook series. These handbooks are entitled *Fundamentals, Refrigeration, HVAC Sysytems and Equipment, and Applications*. Chapter 7 of the *1991 Applications Handbook* contains the most recent health facilities major energy conservation efforts occurring in the industry at that time. A new major topic was added to the end of the chapter entitled "Energy Conservation."

The 1982 chapter marked the beginning of the subdivision of the text into parts. This year had two parts labeled Hospitals and Nursing Homes and although the hospital section had most of the text, the section on nursing homes repeated smaller versions of the tables on air change rates and filter efficiencies. The number of references dropped to nine.

The 1987 chapter, temporarily numbered 23, marked the end of the subheading labeled "The Infection Problem" in favor of a more upbeat "Infection Sources and Control Measures." The text was more useful and specifically mentioned tuberculosis, varicella, rubella, and introduced legionella. The first mention of bone marrow transplant rooms requiring special filtration was mentioned. Ultraviolet sterilizing lamps went from being not recommended in the previous edition to not being mentioned at all. The topic of Design Criteria was divided into "Design Criteria for Principal Areas of an Acute General Hospital" and "Specific Design Criteria by Department." There were no changes to the air change rates in Table 3, but several new spaces were added including an X-ray treatment room and several different variations of laboratory. A new major topic called "Continuity of Service and Energy Concepts" was added and several subtopics like Zoning and Energy were grouped under this heading. A third major part to the chapter was added entitled "Outpatient Surgical Facilities ." This part was added due to the demand for the construction of these facilities. The text under this part mostly referred back to the part on Hospitals. The numbers on the references disappeared and the number of references increased to 14.

The current (1992) edition of the chapter, once again listed as Chapter 7, contains new data about the role of air conditioning in special clinical treatment spaces. For example, in Table 1, a new filter has been added with 99.97 per cent efficiency to be used in orthopedic surgery, bone marrow transplant, and organ transplant service or are further isolated in some remote area of respective patient care units. The room configuration usually includes an attached complete toilet and shower or bath facility the door of which opens into the patient room. Some rooms are also equipped with an ante-room or airlock through which attendant personnel must proceed. Regardless of the concept for constructing the isolation room the importance of having a room with mechanical ventilation is primary. Because of this the design engineer usually provides air in one of a number of ways depending on the guidelines followed. If no guidelines were followed then the need for comfort control of the temperature and humidity are the primary consideration. The ventilation to the patient room most often supplies air from a diffuser in the ceiling or wall. Exhaust ventilation removes air from the room most often from the ceiling in both the toilet and the patient room. Some special purpose rooms use low sidewall exhaust grills. This exhaust air is generally moved directly to the outside of the building and not allowed to be recirculated. The ante-room ventilation is varied with the potential for no ventilation, supply only, exhaust only, or both supply and exhaust. Both AIA and ASHRAE describe the distinction between infectious and protective isolation ventilation. Both guidelines recommend a minimum of six ACH of total air volume in the patient room. In practice, the volume of air supplied is more often dictated by cooling/heating requirements for those systems that are all-air. In larger institutions, the infection control practioner may set larger air volumes for specific infection control reasons such as fungal spore control. The isolation rooms generally are constant volume with reheat to ensure that the specified pressure relationships are maintained. The design may call for a sensing device to control the volume of the air entering the room to favor the exhaust over the supply. Exhaust air is usually removed through grills rather than diffusers partly because of the cost but more so because grills are less likely to clog with debris and are easier to clean. The lack of efforts to keep grills clean often results in the oversupply of air to the room creating an effect opposite to that of containing infectious disease.

ing an effective draft temperature. From this an Air Diffusion Performance Index (ADPI) for the room is determined (ASHRAE, 1990). This index could be used as an indication of good air diffusion for complete mixing of contaminants. This is an important aspect of dilution ventilation.

Most common among the designs for distribution of air in spaces is the ceiling delivery through vaned diffusers and ceiling removal through grills. The factors which influence the ADPI are location of the supply diffusers; their size relative to the quantity of air delivered; the distance the air travels before the velocity decays to less than 50 feet per minute (commonly referred to as the throw); the total quantity and temperature of the supply air; and the location of the return grill relative to the location of the supply. The value of the ADPI is to measure the ability of the air diffusion system to produce an acceptable thermal environment. It could be said that it may also measure the ability of the diffusion system to evenly mix airborne contaminants in the air. The contaminants mixed are those which would otherwise be suspended and not fall to the floor in still air such as droplet nuclei. Research is needed to establish the connection between the homogeneous concentration of infectious particles and the air diffusion systems' ADPI.

Outside Air Rates

One of the more confusing aspects to the guideline recommendations for ventilation is the reference to outside air rates. This is partly due to the fact that the numbers listed in the tables are reported in ACH for both outside air and total air volume. When the standard for acceptable indoor air quality was published, the values listed for outside air quantities were in cubic feet per minute per person (CFM/P) (ASHRAE, 1989). To add to the confusion, both guidelines referenced this standard for minimum volumes of air.

Since most central air handling systems and their distribution ductwork do not generally separate the outside air from the recirculated air, it is not obvious how to comply with delivering ratios of outside air which change from room to room. Central air with infection, e.g., immunosuppressed patients or staff. Quanta have been estimated by calculating from epidemics the effect of the index case and the successive generations of susceptibles who became infected.

- Intubation and bronchoscopy of a TB patient: 249 qph (Catanzaro, 1982).
- Laryngeal tuberculosis in a hospital: 60 qph (Catanzaro, 1982).
- Tuberculosis spread in an office building:13 qph (Nardell, 1987).
- Tuberculosis patient receiving chemotherapy: 1.25 qph (Riley, 1962).
- Measles in an elementary school: 93 qph (Riley EC, 1978).

Any research to establish these quanta should also recommend those values which would be used for the purpose of designing ventilation systems. The quanta so used may be higher than the actual generation rates discovered in research. Room design for infectious particle control should be studied to provide for supply diffuser types and locations along with exhaust locations which would effectively remove airborne infectious quanta. The air change rate and airflow pattern should work in concert to control the release of patient derived infectious airborne particles.

Since undiagnosed TB is a danger anywhere in the health care facility setting, minimum filtration of air everywhere in the building should be set at 90-95%. Outside air rates for every AHU should be set to provide an adequate dilution ventilation for infectious particles too small to filter. Policy should be set for the acceptable calculated risk of infection and the maximum length of stay (unmasked) in the presence of an active TB case.

By establishing these parameters and using the concept of designing to the maximum allowed risk the ventilation engineer can design the ventilation system to the specific requirements of each institution. The minimum recommended ventilation design guidelines should not also be considered the maximum ventilation for everyone.

(TOTAL AIR/OUTSIDE AIR)

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991
D&T											
EXAM		4	4	4	12/6	12/6	12/6	6/2	6/2	6/2	6/2
MED ROOM								4/2	4/2	4/2	4/2
TREATMENT	4	4	4	12/6	12/6	12/6	6/2	6/2	6/2	6/2	
PHYS TRPY					4/4	4/4	4/4	6/2	6/2	6/2	6/2
SOILED HLD		3	3	4	12/4	12/4	12/4	10/2	10/2	10/2	10/2
CLEAN HLD				3	12/4	12/4	12/4	4/2	4/2	4/2	4/2
SERVICE											
FOOD PREP		20	20	20	20/20	20/20	20/20	10/2	10/2	10/2	10/2
WAREWASH					10	10	10	10	10	10	10
DIETARY					2	2	2	2	2	2	2
LAUNDRY		10	10	10	10/10	10/10	10/2	10/2	10/2	10/2	10/2
SOILED LIN		8	8	8	10	10	10	10	10	10	10
CLEAN LIN		8	8	8	2/2	2/2	2/2	2	2	2	2
TRASH CHUTE				10/2	10/2	10/2	10	10	10	10	
BEDPAN RM					10	10	10	10	10	10	10
BATHROOM					10	10	10	10	10	10	10
JANITORS CLO				10	10	10	10	10	10	10	

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RESEARCH RECOMMENDATIONS FOR AEROSOL CHARACTERIZATION

INTRODUCTION

The development and assessment of various engineering control strategies for infectious aerosols depend on an understanding of the biological agent and the carrier particles to which they may be attached. The ability to accurately assess infectious aerosols requires an understanding of how those aerosols behave in the environment. The survivability and vulnerabilities of infectious organisms as they exist in an aerosol form need to be explored. Investigators need to characterize the physical and biological nature of the particles when originally introduced into an environment and when resuspended from previously settled particles. Finally, aerosol control technologies, including filtration and ultraviolet germicidal irradiation, need to be evaluated and applied where appropriate.

These research recommendations for aerosol characterization are the result of two days of discussions by a scientific panel. The panel included scientists with backgrounds and experiences in aerosol physics, microbiology, engineering, and industrial hygiene. The panel began with discussion of Dr. Eugene Cole's paper and plenary presentation on "Aerosol Characterization." Upon concluding their discussion, the panel developed the following general recommendations:

- Characterize infectious aerosols as they emerge from the source.
- Assess physical properties such as shape, size, and aerodynamic properties.
- Improve existing or develop new sampling and analytical methods.
- Study the microbial ecology of infectious agents in the environment.

No program can be successful without extensive *education* of those involved in the design and construction process, as well as those who will ultimately use the facilities. Appropriate educational programs should include the users (specifically, nursing personnel, allied health staff, and physicians), building and systems designers, maintainers, patients, and visitors.

Effective educational programs must encompass several target points: designing the facility, commissioning the building, developing ongoing in-service programs, and caring for patients. The design basis and operational systems must continually be evaluated and explained to those involved in their use and maintenance. Along these lines, the successful education of maintenance personnel will hinge on the complexity of system designs. As funds spent on maintenance decrease, systems must be designed with a minimum of steps and sophisticated procedures in order to allow less educated or skilled personnel to accomplish needed routine maintenance and repair with less frequent activity (i.e., *keep design and systems simple*).

Building system components should be designed as "systems" with overall *performance criteria* instead of individual, discrete component standards. Documentation from this approach should allow users and maintainers over the life of the building to understand the implications of modifying a component on the whole system. Additionally, *building construction must incorporate system maintenance concerns*. As construction funds become tight, owners often cut back on building systems. This approach can negatively affect the ability to provide infection control systems. All parties to the design and construction process should understand the "trade-offs" between first and lifetime operating costs and efficiencies—especially since construction costs are only a small percentage of the total cost of maintaining a building over time. The space allocated to mechanical and electrical systems should be adequate to allow maintenance and repair; periodic maintenance and repair should not have to be compromised because of cramped access.

together and keep panel members on the same track. Again, I want to thank the Program Committee for getting us started; Dr. Larry Doemeny who is my deputy and was our technical coordinator; Ms. Roz Kendall, who was our administrative coordinator and "made it all happen"; Ms. Heather Houston who helped Roz; and other staff at NIOSH; Ms. Charlene Maloney and her staff; Mr. Bob Mueller; Mr. Roger Wheeler; and the other staff who helped in the panel rooms.

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