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

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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Executive Summary

EXECUTIVE SUMMARY

The National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC) convened a workshop during July 14-16, 1993, in Cincinnati, Ohio, to develop a national research strategy on engineering controls for preventing airborne infections in workers in health care and related facilities. The purpose of the workshop was to:

- Review the nature and extent of airborne transmission of infections in workers in health care and related facilities.
- Review current data and new findings regarding the engineering control of airborne infections that may have relevance to occupational exposures in health care and other institutions.
- Identify knowledge gaps that might be filled by directed research.
- Recommend a national research agenda that, if implemented, would close the gaps and permit reliable recommendations for protecting workers.

Approximately 400 individuals attended the workshop, including 125 from governmental agencies, 40 from academia, 150 from health care and related facilities, 25 consultants, 30 from labor organizations and 40 from the insurance industry, architectural firms, etc. The mix of expertise included infection control practitioners, industrial hygienists, physicians, nurses, epidemiologists, engineers, architects, front line health care professionals and other workers from health care facilities.

Two keynote papers were presented: "Perspectives on Airborne Infections in Health Care Facilities" and "A Perspective of Ventilation for Health Care and Related Facilities." These two papers provided the workshop participants and attendees with a general overview of the issues of airborne transmission of infections

and engineering (ventilation) controls for preventing such transmissions.

Four plenary papers were presented, each addressing a specific aspect of preventing airborne infections in workers. The four plenary presentations covered:

- Aerosol characterization.
- Source characterization and source control.
- Building designs.
- Ventilation designs.

Panels of experts in the four areas, using the information presented in the plenary papers and the background information from the keynote papers, focused on the development of a national research agenda.

These Proceedings, then, serve as a report to the Nation based on the interaction and discussions that occurred during the workshop among occupational health specialists, infection control specialists, engineers, architects, academicians, administrators and workers. This document will provide a lasting record of the excellent keynote and plenary papers that were presented, and will focus research on the needs that were identified for worker protection. These Proceedings provide the reader with the following information:

- An executive summary which highlights the findings from the workshop.
- Introductory and summary comments from the workshop co-chairs.
- The two keynote and four plenary papers which served as the basis for the panel discussions.
- The research recommendations which resulted from the panel deliberations.

HIGHEST PRIORITY RESEARCH NEEDS

It was recognized that the "engineering" research needs identified in this workshop were not unusual for the occupational/environmental health and infection control fields. However certain general issues and priority areas were identified by all four panels. These are summarized as follows:

- The need to be able to characterize and assess the various properties of the aerosols (e.g., size, shape, aerodynamic properties, survivability).
- The need for sampling and analytical methods for use in determining exposure levels and efficacy of controls.
- The need to be able to rapidly identify infectious sources (e.g., patients, workers, contaminated surfaces, etc.) so that appropriate control technique(s) can readily be applied.
- The need to determine the efficacy of various control techniques (administrative and engineering controls) individually and/or collectively.
- The need for criteria and methodologies for designing (new and retrofit) inpatient isolation and intensive care rooms, surgical suites, emergency rooms, waiting rooms, etc.
- The need for special design criteria and control techniques to protect worker groups outside of the usual definition of health care worker (e.g., workers in social service settings and correctional settings and maintenance and hazardous waste workers) and for high risk workers, (e.g., immunocompromised individuals).

Also, it was recognized by all participants that there is a need to assemble all the relevant knowledge and expertise that is available in the infection control practitioner community, the occupational health community and engineering/architecture community to solve this workplace problem. Interdisciplinary interaction needs to be stimulated for consolidation of known

information and identification of residual research needs. The knowledge that already exists among the professional and worker communities, mentioned above, needs to be collected and shared so as to provide direction and solutions to immediate problems. There is a considerable amount of knowledge that exists but is not being applied; a universal data base is needed for all to use.

The various components of the recommended research agenda do not have to be conducted in sequence. However, it should be noted that without (1) better exposure assessment tools for estimating dose, (2) better knowledge about exposure levels, and (3) better knowledge about the relevancy of exposure levels to disease risk, there will be limitations in the ability to prevent airborne transmission of infectious agents. Implementation of this research agenda should not postpone efforts to implement prevention strategies that are now available and feasible.

SUMMARY OF RESEARCH NEEDS

The major research needs in each of the four program areas that were discussed at the workshop are highlighted below.

Aerosol Characterization

- **Characterize infectious aerosols as they emerge from the source**

  To validate laboratory studies with test organisms, the carrier particles need to be matched to real-world particles.

- **Assess physical properties such as shape, size, and aerodynamic properties**

  To develop sampling and analytical methods, the size, shape, and viability of infectious agents need to be understood.

- **Improve existing or develop new sampling and analytical methods**

  To control exposure, to evaluate controls, or to identify potentially hazardous conditions, technologies for rapidly and reliably assessing the presence and quantity of infectious agents are needed.

- **Study the microbial ecology of infectious agents in the environment**

  Factors that regulate growth, including organism response to drugs, disinfectants, and ultraviolet light, provide insight into control strategy options. The ability of organisms to survive in sample collection devices also may represent a significant problem. For viable sampling methods, the organisms must maintain their ability to reproduce and grow following impaction, impingement, and possible desiccation on a filter or other sampling surface.

- **Select model pathogens for use in testing sampling methods and controls**

  There is a need to identify and select model pathogens for use in testing sampling methods and control technologies. Models for bacteria, fungi and viruses may be needed. Pathogens of concern that require model organisms include, but are not limited to *M. tuberculosis, Legionella, Aspergillus*, and rubella, influenza, varicella, adenoviruses, and measles.

- **Evaluate control technologies, individually and in combination**

  To improve on infection controls, research on the effectiveness of various control technologies,

individually and in combination is needed. Control strategies currently proposed include ventilation (local and general), HEPA filtration, ultraviolet germicidal irradiation, and respiratory protection. Efficacy of these techniques needs to be proved.

- **Evaluate the performance of filtration control**

  The efficacy of filtration, including HEPA filters, and the use of respiratory protective equipment needs to be assessed. The penetration and viability of organisms as they pass through filters needs to be evaluated.

- **Characterize and assess resuspended aerosols**

  The survivability of infectious agents on surfaces, clothing, bedding materials, etc., which may be contaminated with infectious agents that have the potential to be re-aerosolized, needs to assessed. Research also should focus on fungi for aerosolization from surface growth.

Source Characterization and Source Control

- **Identification of infectious sources**

  The major source for the transmission of airborne infections in health care and related facilities is infected persons. The bacteria or viruses may be exhaled as the person talks, coughs, or sneezes. Microbial contamination of ventilation systems, while a contributing factor in potential nosocomial infections in immunocompromised persons, has not been commonly reported in workers as a result of work-related exposures. Thus, prompt identification of infectious individuals is of utmost importance.

- **Epidemiology and surveillance studies**

  The adequacy of infectious disease surveillance systems (i.e., identification of patients known to be infected) in local and state health departments needs to be evaluated. A prospective surveillance system for tuberculosis skin test conversions in health care facilities (e.g., possibly National Nosocomial Infection Control System-based [NNIS-based]) needs to be established. Follow-up studies of exposed workers need to be conducted to better understand the sources of airborne infections and the efficacy of current control procedures. Epidemiologic studies need to be conducted of worker tuberculin skin test conversions in "related facilities" to identify the risk of acquiring TB infection in these settings.

- **Engineering and procedural controls**

  Many of the source control methods used to prevent airborne transmission of infectious diseases involve procedural as well as engineering methods of controlling exposures. The major engineering and procedural control research included the need to:

  1. Evaluate existing and develop novel control methods for special high risk procedures such as sputum induction, bronchoscopy, patient transportation.
  2. Evaluate efficacy of recirculation units (i.e., in-duct air filtration and ultraviolet germicidal irradiation [UVGI]).
  3. Evaluate auxiliary exhaust units (i.e., in-duct or in-room, ventilation systems used to augment general ventilation) via field evaluations and epidemiologic studies.
  4. Develop performance criteria and testing protocols for portable, stationary, and in-duct high efficiency

particulate air (HEPA) and ultra-low penetration air (ULPA) filtration units.

5. Evaluate performance and provide information on available filters and filtration systems;
6. Evaluate personal safety and efficacy issues of UVGI disinfection of air (i.e., upper-air and in-duct irradiation).
7. Evaluate the adequacy of the Wells-Riley equation for estimating the risk of acquiring tuberculosis infection and modify the equation, if necessary;
8. Evaluate airflow patterns within the rooms and their impact on local variation of infectious aerosol concentration within the rooms.
9. Develop a national respirator task force to discuss and make recommendations on the types and use of respirators by patients, health care workers and visitors.
10. Conduct hazard assessment of medical waste disposal workers at health care and medical waste disposal facilities.

- **Education**

  Training and education are important factors in an infection control program. Evaluation and revision of current materials and techniques are needed to meet the objective of preventing the transmission of all infectious agents. The use of these materials should be directed toward practioners in infection control, industrial hygiene, and facilities engineering; and also toward patients, clients, workers, inmates, and others.

- **Recommendations not otherwise classified**

  These recommendations did not fall under one of the other four major areas of research. Issues which need to be addressed include special

considerations of individuals covered under the Americans with Disabilities Act (ADA), compliance with infection control procedures, and overall management of an infection control program.

Building Designs

- **Interim control measures**

  Immediate interim methods need to be developed for improved worker and patient protection until new construction, renovation, and/or other initiatives are developed for medical centers and related facilities such as homeless shelters, ambulatory care, methadone clinics, etc.

- **General facility planning**

  Methodologies need to be developed to calculate the number of inpatient acute and intensive care infectious isolation rooms, both on a regional health planning basis and also on a hospital or network-wide basis. Also, methodology needs to be established to identify hospital based ancillary service needs and alternate care delivery sites. In addition, criteria and programmatic needs for the layout and location of infectious isolation and related facilities need to be developed.

- **Isolation suite anteroom design**

  It should be determined whether anterooms are necessary in isolation suites, and how they should be designed and physically located in regard to the isolation suites.

- **Existing buildings**

  Strategies need to be developed for converting existing buildings to meet the criteria and programmatic needs of protecting health care workers and patients from airborne infections.

- **Treatment room design**

  The appropriate design criteria and technology need to be determined for areas where sputum induction, administration of aerosolized medications, and other high risk procedures are performed, such as booths, specialized rooms or enclosures (bronchoscopy and pentamidine administration).

- **Long-term treatment/isolation facilities**

  Performance criteria need to be developed for designing facilities for patients having a long-term need for treatment or isolation (e.g., need for living space, recreational facilities, movement around the facility).

- **Ancillary service and "other" facilities**

  The effect of prolonged or repetitive contact with high risk clients on the health of health care and/or social service workers should be studied. Also, the probability of workers and clients acquiring airborne infections in overcrowded conditions (e.g., places of assembly, transportation, homeless shelters, day rooms, etc.) should be studied. In addition design criteria for prolonged contact waiting spaces (e.g., initial patient screening, emergency department holding areas, public waiting spaces, etc.) should be developed.

Ventilation Designs

- **Pathogen generation rates and concentration control levels**

  The application of effective control technology requires knowledge of the level of contaminant being generated and a concentration level limit. These levels are not well known for airborne infectious organisms and need to be determined.

- **Identification of ventilation rates and distribution of general ventilation airflow**

  Research is needed to determine the feasibility of utilizing the Wells-Riley equation to establish appropriate ventilation rates. The effect of airflow level in reducing contaminant levels in a space needs to be researched. Detailed information is needed on the effects of air distribution, such as comparison of displacement vs. dilution ventilation.

- **Local exhaust ventilation**

  Research is needed to determine how to apply open type hoods to treatment procedures such as bronchoscopy.

  Research is needed to determine efficacy of portable cleaning devices and to develop standards for maintenance and operation of both patient enclosures and portable cleaning devices.

- **Filtration**

  Research is needed to determine the application and effectiveness of filtration of various infectious disease organisms, and the safety aspects of filter maintenance.

- **Containment**

  Research is needed on determining the proper airflow balance in a room to achieve adequate levels of negative pressure and the need for anterooms (and anteroom airflow balance).

- **Maintenance guidelines and performance monitoring**

  There is a need to develop maintenance guidelines and system monitoring techniques focused on health care ventilation systems which can be readily implemented to prevent system breakdown.

- **Ventilation control system design**

  Research on how to properly operate and maintain facility ventilation systems throughout an entire facility is needed.

- **Side effects of engineering controls**

  A study of the side effects of existing and new engineering controls should be conducted to identify acceptance problems and to recommend corrective procedures which will aid in acceptance of the control.

- **Role of ultraviolet irradiation in infection control**

  Research should be conducted to evaluate the efficacy of UV irradiation in killing airborne infectious organisms and to develop parameters (dose response) to permit its effective application. Recommendations also need to be developed for safe operation and maintenance of the UV systems.

- **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.).

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WORKSHOP OPENING
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CHARGE TO PARTICIPANTS

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.

You are all aware that infectious disease in the health care industry is more than a problem on the horizon. It is an issue which demands our immediate attention. We have clearly seen this in issues related to Hepatitis B and HIV transmission. And now drug-resistant tuberculosis is making itself felt as a threat to workers in hospitals and other health care settings.

Controlling this problem will require the best expertise of infectious disease controllers, industrial hygienists, and engineers. Three varied disciplines, with their different traditions and cultures, will have to unite for a common goal. This must be successful in order to assure the protection of workers as well as patients. We can expect that this confluence will not be without turbulence as these three disciplines grope for a common language, common understanding, and common methods of proceeding. To put it quite simply, we will frequently be sailing against the wind. But what really matters is that we will be sailing—not merely drifting or lying at anchor.

The ship that will carry us is engineering controls. We have chosen this vessel for many reasons. It is engineering controls that are the ideal method for controlling the transmission of infectious disease among workers. If we can count on engineering controls to be the method of prevention, then workers will not have to rely on personal protective equipment, which often has many unreliable features. Nor will they have to learn and follow tedious guidelines or prevention measures. It is crucial to remember that something very basic lies at the heart of our efforts here today: the safety and health of workers. This is why NIOSH decided to convene this workshop. It is both our nature and our mission to preserve the lives of workers.

Twenty-three years ago, Congress made a national commitment to the welfare of the American worker. On December 29, 1970, Congress passed the Occupational Safety and Health Act of 1970, promising to "provide safe and healthful working conditions for every working man and woman." It also created NIOSH and our

sister agency, OSHA.

OSHA and NIOSH are both dedicated to the prevention of occupational diseases and injuries; however, we are different in many ways. OSHA is in the Department of Labor and is primarily responsible for promulgating and enforcing occupational *standards* to protect workers from the hazards of work. Thus, OSHA does risk management.

In contrast, NIOSH was created by Congress to be a scientific institute and was placed in a different department, the Department of Health and Human Services. The mission of NIOSH is distinct from that of OSHA. Congress charged NIOSH to do four things:

- *Research* on occupational diseases and injuries.
- *Respond* to requests for assistance by investigating problems of health and safety in the workplace.
- *Recommend* standards to OSHA based on scientific findings.
- *Train* professionals in this field.

As NIOSH fulfills these responsibilities, we are supported by a vision, which guides our culture and research: *"Delivering on the Nation's Promise: Safety and Health at Work for all People. . . through Prevention."* This vision propels us to fulfill our mandate of protecting all the workers in this country from occupational disease, death, and injury.

In short, NIOSH is the only national health institute with the responsibility to exercise national scientific leadership in protecting the health of workers. We feel a sense of obligation to workers to assure that they are working in the safest possible conditions. This meeting will help us carry out that role.

It is my and Dr. Millar's sincere wish that when we leave this workshop, we will return to our varied disciplines with a real feeling of accomplishment. We will have a better idea of the real

nature and extent of infections in workers in health care and related facilities and of how engineering controls can protect them. We will have developed a national research agenda that will close the gaps and permit reliable recommendations for protecting workers. In short, we will be sailing towards a feasible solution.

But perhaps most importantly, we will realize how our collective knowledge can prevent these workers from disease and death. Zhores Medvedev, the imminent Soviet biologist, once wrote: "As science progresses, the worldwide cooperation of scientists and technologists becomes more and more of a special and distinct intellectual community of friendship, in which, in place of antagonism, there is growing up a mutually advantageous sharing of work, a coordination of efforts, a common language for the exchange of information, and a solidarity. . . ." It is our hope that this precedent-setting meeting will create this kind of solidarity between industrial hygiene, engineering, and infectious disease for the good of the workers.

Now I close by thanking several people for the inspiration and perspiration they put into this meeting. First, Ms. Roz Kendall of NIOSH, who handled the thousand and one logistical details. Next, Co-Chairs Dr. Morton Lippmann of New York University Medical Center and Philip Bierbaum of NIOSH, who organized the meeting and were instrumental in the selection of the presenters and program content. And now I call on Phil and Mort to carry us forward.

WORKSHOP AGENDA AND CHARGE — PHILIP J. BIERBAUM

Thank you very much Dick; we appreciate the time you took to come and be with us at this important workshop.

I am Phil Bierbaum and, as Dick indicated, one of the co-chairs of the workshop. I am the director of the NIOSH Division of Physical Sciences and Engineering and I welcome you to my home here in Cincinnati and to the location of one of the major facilities of NIOSH.

What I am going to do this morning, for about 10 minutes, is to take you through what we want to do for the next several days, the logistics of what we want to do, the agenda, the format, etc., and explain how we hope the workshop will evolve. Then I will introduce Dr. Lippmann, my co-chair, so that he can present his views on why we are here and his vision about the workshop.

The first thing I want to do is to make sure everybody has an information packet about the workshop. You should have received this packet when you registered today. The packet includes the workshop program, keynote and plenary papers, a list of pre-registrants, and information about Cincinnati. Also, at the back of that workshop program, you will find a list of our panel members who will help us during the workshop, and also a list of the Program Committee, that Dr. Lippmann and I co-chaired, who selected the speakers and developed the workshop program and format. So, I would appreciate it if you would look through the packet.

Before I go through the program and the format, I want to re-emphasize what Dr. Lemen just said about why we are here and the purpose of the workshop, which was stated in our preliminary workshop announcements. The purpose of the workshop (and if you bear with me I will read it so that I can emphasize various points) is to:

- Review the nature and extent of airborne transmission of infections in workers in health care and related facilities.
- Review current data and new findings regarding the engineering control of airborne infections that may have relevance to occupational exposures in health care and other institutions.
- Identify knowledge gaps that might be filled by directed research.
- Recommend a research agenda (not just one for CDC and NIOSH, but a national research agenda that all of our constituencies and peers can use) that, if implemented, would close the gaps and permit reliable recommendations for protecting workers.

One additional point I would like to make in regard to a "charge" for the workshop. We need to go beyond health care facilities with our recommendations. Correctional facilities, social service facilities and other related facilities also need to be considered. There is even more knowledge needed about what to do for engineering controls in these other facilities as compared to "health care facilities."

I now would like to go through the program with you. This morning we have two keynote speakers: one discussing a perspective on airborne infections and the second on engineering controls (emphasizing ventilation). This does not mean that the papers are all encompassing or that you all will agree with what is said, but the speakers will present their perspectives on the two issues. Then, later this morning, after the break, we will have four plenary speakers who have developed what we will call "discussion papers." These papers will be used by our panel chairs and rapporteurs to lead our panels through their "working deliberations" that will start this afternoon and will end on Friday morning. The four panels we have established are "Aerosol Characterization," "Source Characterization and Control," "Building Designs," and "Ventilation Designs." The plenary speaker will

present their viewpoints on these four specific issues this morning. There will be no reaction to the papers at this point; they are being shared in this plenary session so that attendees hear all the papers at the same time. Then this afternoon, the panels will begin their deliberations.

Our goal during the panel deliberations is to have the plenary speakers go through their papers again so that the panels can get started in regard to reacting to the recommendations of the plenary speakers; this process will take place over the next day and a half, and the panel chairs and rapporteurs will lead the panels through the process with the ultimate goal of developing the research agenda. We have used this format in the past and it has been successful; we are anxious to see if it works in this forum.

There probably will be an overlap across the four areas; if there is an overlap, it will evolve as we go through the summary presentations on Friday. Also, we have a session that is not listed in the program for just the panel from eight to nine tomorrow morning. This session is planned to let the panels see what kind of overlap there might be and to get some feel for missing information in case we need to redirect panel chairs and rapporteurs.

Again, on Friday morning, after we have gone through this iterative process, the panel chair and rapporteurs for each panel will spend a half hour or so summarizing their panel's specific recommendations. Then, Dr. Lippmann and I will each provide a 10-15 minute synopsis of where we think we are and an overall workshop summary. Hopefully, in 3 or 4 months after all of the material is put together, we will publish a Proceedings.

For the attendees that are not participating on the panels, there will be time set aside for your comments and questions that can be added to the panel deliberations. Usually this comment and question period will be at a certain point in each of the sessions. The chair and rapporteur of each of the panels will control this time period to make sure that we stay with the time we have allotted.

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.

WORKSHOP CHARGE — MORTON LIPPMANN

It's a pleasure to welcome all of you to this workshop, which is the culmination of more than a year of planning. Its genesis was at an informal meeting that I had with Don Millar in May of 1992, after his keynote presentation at the annual American Industrial Hygiene Conference and Exposition. Dr. Millar's keynote address discussed the history of infectious disease control and the opportunities that were being missed because of a separation into different professional fields that don't normally communicate enough with each other. I suggested to him that the NIOSH Board of Scientific Counselors would be very interested in helping address such needs, especially in the case of the national need to reduce the spread of multi-drug resistant tuberculosis. We agreed that there was a particularly urgent need to protect workers' health in the health care industry, and that by combining the talents of NIOSH in ventilation control of airborne contaminants, and the general interest and expertise in other areas of CDC in recognizing and controlling infectious disease, real contributions could be made. With the enthusiastic support of Dr. Millar, other members of the Board, and several people on Phil Bierbaum's staff, we initiated a series of Program Committee meetings. Their product is this workshop.

We made a major effort to identify the speakers at an early stage. We could thereby commission the writing of the background plenary and keynote papers early enough for them to be received and distributed to all of the members of the workshop panels in advance to help simulate the panelists' thoughts on these topics. We hope that the workshop will produce consensus views and recommendations. I want to thank all the authors. They have done their jobs very well, and have given us excellent discussion papers.

This is an unusual workshop in many ways. We come from various scientific disciplines and need to learn how to communicate more effectively with each other. Part of our problem is that

we often don't know the literature in each others' fields. As a result, we can't make as much contribution to solving our own parts of the puzzle as we could if we had a more comprehensive understanding of the larger issues. This workshop provides an opportunity for us to get to know each other better and to interchange our ideas, thoughts, and knowledge.

We expect the Proceedings of this workshop to prove to be an extraordinarily valuable resource. The publication of these Proceedings will make available a reference book containing the state-of-the-art papers and their bibliographies, as well as the panel session summaries and recommendations. Thus, this workshop represents a starting point for this diverse group of professionals to start to develop common actions for addressing urgent worker health needs.

We on the Program Committee still have more work to do in pulling together the written contributions already made and the workshop summaries into a publication that will be useful to each of you. We expect that the Proceedings will be distributed widely, and that it will have a beneficial impact on the national research agenda in this area. I believe that we have all come here with open minds, and are ready to learn and absorb what our colleagues from other disciplines have to teach.

Part of the problem we face is that we have relied for too long on old ideas and assumptions. Many of them are difficult to justify when they are challenged, because they're based on general concepts and beliefs rather than on data. What we need is more relevant data to either confirm or refute these assumptions, so that we can move ahead and be able to address the research agenda in a more productive way.

Airborne infection in health care facilities has not been adequately recognized as a major problem. One result is that appropriate control technology has not been validated or refined. Part of the problem is chronic underfunding of research. If advances beyond

current knowledge are to be made, we are going to need to devote significant resources for a research agenda. We, as individuals, need to speak to our professional organizations and to the larger community about collective efforts to address the urgent national need to control airborne infection. Clearly, the public is interested in the spread of multi-drug resistant tuberculosis (TB), but if we focus only on TB, we would be missing a larger opportunity. If, in addressing and correcting some of the problems of transmission for TB, we put in place systems that will reduce all hospital acquired infections we will not only avert mortality and pain and suffering, but make a real contribution to ameliorating our health care cost containment crisis. When people spend extra weeks in the hospital because of acquired infections, there are substantial monetary costs as well as professional embarrassment and patient pain and suffering.

We have assembled a truly outstanding list of speakers for today's morning session and we now need to proceed.

KEYNOTE ADDRESSES

PERSPECTIVES ON AIRBORNE INFECTION IN HEALTH CARE FACILITIES

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INTRODUCTION

This presentation has four objectives: first, to place current beliefs about airborne nosocomial infections into an historical context; second, to review the possible sources of airborne infection in the health care setting; third, to review the microorganisms that have been transmitted by the airborne route in hospitals; and finally, to evaluate the relative importance of airborne transmission of infection in the overall problem of nosocomial infection.

HISTORICAL CONTEXT

Any presentation entitled "Perspectives on - - - " must acknowledge the cyclic nature of beliefs about the routes of transmission of infectious diseases (Riley, 1980). In 400 BC., Hippocrates believed that airs, waters and places influenced the health of populations. In the second century AD., Galen noted that when many sicken and die at once, one should consider the air that we breathe. His observations were underscored by the occurrence of dreaded epidemics such as The Black Death in Europe during the

14th century. Two hundred years later, Fracastorius noted that infection could be transmitted by direct contact, by indirect contact, or from a distance, that is, through the air.

For the next several hundred years, airborne infection was thought to be a major route of transmission, and so the "miasmic" theory of infection gained credence, leading to names like "malaria." After the microbial nature of infectious diseases was recognized in the mid-nineteenth century, the role of contact in infection transmission was clearly identified, and gained rapidly in acceptance. By 1910, Charles Chapin could write in his treatise *On the Sources and Modes of Infection* (Chapin, 1910): "Without denying the possibility of [airborne] infection, it may be fairly affirmed that there is no evidence that it is an appreciable factor in the maintenance of most of our common contagious diseases. We are warranted, then, in discarding it as a working hypothesis and devoting our chief attention to the prevention of contact infection." He did waver a bit in the case of tuberculosis, however, and considered that disease more likely than any other to be airborne.

Chapin's views persisted for the next 35 years. In 1935, however, William Firth Wells, an engineer at Harvard, began to challenge this dogma (Langmuir, 1980) and began to argue that certain diseases, such as measles, were spread through the air by droplet nuclei. Ultraviolet lights were introduced into a few schools to test this hypothesis, and were met with at least initial success. As recently as 1946, however, a committee of the American Public Health Association wrote, in its final report, that: "Conclusive evidence is not available at present that the airborne mode of transmission of infection is predominant for any particular disease" (Subcommittee Report, 1947).

The next twenty-five years, of course, sharply changed beliefs about airborne transmission of infectious disease, and put epidemiological theory on a more scientific basis. Alexander Langmuir, in a thoughtful review (Langmuir, 1980), identified four areas of study that have led to a more substantive understanding of the role

of airborne infection. These included, first, an understanding of the creation and behavior of aerosols of micro-organisms; second, an understanding of the physiology and function of the respiratory tract, particularly the respiratory host defense mechanisms; third, the study of experimental airborne infections in animals and man; and lastly, increased understanding of the epidemiology of both naturally occurring and accidentally acquired infection.

Knowledge and understanding of the role of airborne infection in the health care setting has generally paralleled understanding of the role of airborne infection more generally. In fact, it is probably fair to state that studies of nosocomial infection transmission have often been pivotal in understanding the broad role of airborne infection. The classic studies of Richard Riley in the Baltimore Veterans Administration Hospital (Riley, et al., 1959, 1962), for example, were critical to understanding the airborne transmission of tuberculosis in any setting.

Sources of Airborne Infection in Hospitals

Possible sources of airborne nosocomial infection are summarized in Table 1. Within the hospital the most important and most

Table 1. Possible Sources of Airborne Nosocomial Infection*

Inside the hospital:	Outside the hospital:
•Infective dusts, aerosols •Infected or colonized patients, staff, visitors •Ventilation or air conditioning systems	•Soil •Dust from construction, renovation •Decaying organic materials •Water (e.g., cooling towers)

*Modified from Schaal, 1991.

obvious sources are human beings, either patients, personnel or visitors. To be an efficient source of airborne infection, a person needs to be a disseminator or spreader of some pathogenic organism. Such a disseminator may be a person with symptomatic

disease, as has been described in nosocomial outbreaks of tuberculosis and smallpox; alternatively, a disseminator may be wholly asymptomatic, a kind of microbiological "Pigpen," to recall the name of the well-known Peanuts character. Such asymptomatic carriers have been well described as sources of airborne nosocomial staphylococcal infections. Sites from which airborne dissemination has occurred include the nares, pharynx, anus, skin and skin scales. Other possible sources of airborne infection within the hospital include dusts or aerosols from the floor or furniture, from potted plants or flower vases, sinks, showers, nebulizers, humidifiers, or aspirating devices. Contaminated ventilation or air-conditioning systems have been implicated in some nosocomial airborne outbreaks, via infective aerosols, dust, or even colonized filters (Schaal, 1991).

Outside the hospital, there are a number of possible inanimate sources as well. These must include soils, acting either as a natural habitat of certain pathogens, or soil that has been contaminated by feces. Water supplies may be contaminated by potential pathogens and the contaminants may then be amplified in certain settings such as cooling towers, or in holding areas within the hospital. Legionnaire's Disease has been spread both by the airborne route from contaminated cooling tower water, and by the generation of infective aerosols from water supplies within the hospital. Infective dusts may be generated from building construction or renovation activities within the hospital, or located in immediately adjacent areas. In general, airborne nosocomial pathogens derived from the inanimate environment have been less virulent than those derived from animate sources, and have tended to occur primarily in areas in which very highly susceptible hosts are located, e. g., oncology units, organ transplantation units, and the like. Furthermore, the number of pathogens that can spread via the airborne route from dusts, soils, or construction areas appears to be limited to a few bacteria and fungi that can survive in a dry environment for extended periods of time.

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.

Since the eradication of smallpox, any consideration of nosocomial airborne transmission of this disease is probably of only academic interest. That this has occurred, however, is established beyond any doubt. In 1970, a major outbreak of smallpox occurred in a small hospital in Meschede, West Germany; a single index patient infected 17 other persons, including both patients and personnel. Two additional cases occurred in a second generation, a total of 19 cases, with three deaths. Using a smoke generator, the investigators showed that aerosols from the index patient's room spread not only out of the window, but also into the corridor, up a stairwell and into patient rooms on floors above (Wehrle, 1970). Ironically, the very last case of smallpox in the world was due to airborne transmission, a tragic laboratory accident that resulted not only in the death of the victim, a 40-year old medical photographer in the Medical School at the University of Birmingham, England, but also in the suicide of the smallpox laboratory director (Centers for Disease Control, 1978; Hawkes, 1979).

Table 2.

Viruses implicated in Airborne Nosocomial Infections	
Rhinoviruses	Measles
Influenza and parainfluenza viruses	Rubella
Respiratory syncytial virus	Smallpox
Adenoviruses	Varicella-zoster virus
	Certain enteroviruses

There are theoretical concerns to be raised about possible spread of viral hemorrhagic fevers such as Lassa fever or Ebola virus disease transmission via the airborne route in the hospital setting, but evidence in support of this possibility is fragmentary (Ayliffe and Lowbury, 1982). The recent outbreak of Hantavirus-associated Adult Respiratory Distress Syndrome in the southwestern part of the United States (Centers for Disease Control and Prevention, 1993) also raises such concerns, which thus far seem to have been entirely theoretical.

There is some evidence that certain enteric viruses may be transmitted through the air. Particularly intriguing was an outbreak of what apparently was Norwalk-like virus gastroenteritis that occurred in a 600-bed general hospital in Toronto, Ontario in November, 1985 (Sawyer, et al., 1988). The outbreak occurred over a three-week period, and involved 635 hospital personnel, over a quarter of the staff. No common food or water source was found, and the investigators concluded that spread of the organism within the hospital was probably by the airborne route.

Although a theoretical possibility, there is no evidence to support transmission of blood-borne viral pathogens such as Hepatitis B virus or HIV through generation of aerosols in blood banks, patient care areas, operating rooms, or laboratories.

Moving up from viruses, there is one rickettsial agent that should be mentioned, that being *Coxiella burnetti*, the etiologic agent of Q fever. This organism has never been transmitted in the hospital setting, to my knowledge, but it has caused airborne infection in medical school research laboratories that used parturient sheep to study perinatal physiology. In a 1980 outbreak at the University of Colorado Health Sciences Center (Meiklejohn, 1981), most of the 137 cases occurred in staff members working in laboratories or offices along the routes used in transporting sheep to their destination.

Bacteria that have been implicated in airborne transmission in health care facilities are shown in Table 3. Evidence in support of airborne transmission of bacteria is generally easier to obtain than in the case of viruses, simply because it is technically easier to recover bacteria using air sampling techniques. Yet, it must be remembered that the mere demonstration of viable bacterial pathogens in the air does not establish that airborne transmission has occurred.

Bacteria that may be transmitted airborne directly from infected persons or healthy carriers include Group A streptococci, *S. aureus*, the meningococcus, *C. diphtheriae*,

Bordetella pertussis, and, of course, *Mycobacterium tuberculosis*. Bacteria that may be airborne from dust particles or from aerosols generated within the hospital include again *S. aureus*, tubercle bacilli, other mycobacteria, nocardia species, pseudomonads, enteric bacteria, and *Legionellae*. Contaminated or colonized ventilation or air-conditioning systems have resulted in airborne spread of *Legionellae*, pseudomonads, *Clostridia, Nocardia*, and probably *Chlamydia psittaci* (Schaal, 1991).

Among the bacteria spread directly from infected persons, patients or personnel, or from asymptomatic carriers, *S. aureus* and tubercle bacilli are by far the most important. Airborne staphylococcal infection in hospitals have been particularly important in two settings: nurseries and operating theaters. Key experiments documenting airborne spread of staphylococci in

Table 3. Bacteria that Cause Airborne Nosocomial Infection*

From patients, staff, visitors:
- Group A streptococcus
- *Staphylococcus aureus*
- *Neisseria meningitidis*
- *Bordetella pertussis*
- *Mycobacterium tuberculosis*

From infective aerosols:
- Pseudomonads
- *Acinetobacter*
- *Legionellae*
- Other non-fermenters

From ventilation / air-conditioning systems:
- *Legionellae*
- *Clostridia*
- *Norcardia*

* Modified from Schaal, 1991.

nurseries were carried out by Mortimer and his colleagues in the early 1960s (Mortimer, 1966). In recent decades, however, staphylococcal cross-infection in nurseries appears to have become less prominent.

In contrast staphylococcal post-operative wound infections remain a major problem, particularly in procedures involving the insertion of prosthetic devices, including joints and valves. There remains a great deal of controversy, however, as to the relative contribution to the problem made by airborne transmission of staphylococci, as compared to transmission by direct or indirect contact. For example, when total hip arthroplasty was first introduced, post-operative infections, mostly due to staphylococci were unacceptably frequent. Using ultra-clean vertical laminar airflow plus exhaust-ventilated clothing in the operating room, Charnley and his co-workers were able to show a striking reduction in post-operative sepsis rates from 9% down to 1% (Charnley and Eftekhar, 1969). Critics, however, pointed out that there were no concurrent controls in those studies, and that several other changes were introduced during the study period. Surgeons improved their skills as they gained more experience, operative techniques were changed, and operation duration decreased (Ayliffe and Lowbury, 1982). Furthermore, in some other centers where ultra-clean air was not used for total hip arthroplasties, infection rates were comparably low (Fitzgerald, 1980).

The role of airborne bacteria in operating rooms as major determinants of post-operative wound infection rates in other kinds of surgical procedures remains controversial as well. Some surgeons in the United States, notably Deryl Hart, at Duke University, were so convinced of the significant role of airborne transmission that they installed ultra-violet lights in their operating rooms (Hart, 1960). Published data suggested that the use of UV lights in those operating rooms was associated with a very low rate, approximately 0.5% of infection in so-called "refined clean wounds," a category of surgical wounds in which one would expect an infection rate of 1.0% or less (Goldner, 1980).

The National Research Council in the 1960s sponsored a multi-hospital controlled trial of the role of UV light in preventing post-operative wound infection (National Research Council, 1964). The results suggested that there was indeed a reduction of the rate of post-operative infections in "refined clean wounds," from 3.8% to 2.9%, but this category of wounds represented only 19 % of all infections studied; thus this modest beneficial effect was lost in the over-all experience in the study, and was offset by an apparent detrimental effect of UV light in non-clean wounds. Ultraviolet light was effective, however, in reducing the counts of airborne bacteria in the operating rooms.

Controversy about the relationship of quantitative bacterial counts in the operating room and the risk of subsequent development of sepsis continues. Lidwell and his colleagues in Great Britain found a good correlation between the level of air contamination and subsequent sepsis rates in joint replacement procedures (Lidwell, et al., 1983). Fitzgerald and colleagues at the Mayo Clinic were not able to relate the level of airborne bacteria to the risk of wound sepsis; they have, however, noted that older operating rooms with lower rates of air exchange seemed to have higher post-operative infection rates than newer rooms, with higher rates of air exchange (Fitzgerald, et al, 1977).

In 1993, the most serious threat in airborne nosocomial infection is that posed by *Mycobacterium tuberculosis*. The nature of the threat is clear enough, and is highlighted by a number of recent investigations of hospital outbreaks of multi-drug resistant tuberculosis (Dooley, et al., 1992; Pearson, et al., 1992; Edlin, et al., 1992; Beck-Sague, et al., 1992). All of them have been associated with highly immunosuppressed AIDS patients acting as index cases, and spread occurred within the hospital to other AIDS patients, patients highly immunosuppressed for some other reason, and to hospital staff. In one instance, a health care worker with HIV infection and tuberculosis was the index case in a major outbreak in a city hospital (Zaza, et al., 1992). Even before the AIDS epidemic, there was already abundant evidence that

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).

There is abundant evidence that *Pneumocystis carinii* may be transmitted via air in animal experiments. There is circumstantial evidence that it has been transmitted in nursery settings. There is no direct evidence, however, that *Pneumocystis carinii* is a significant nosocomial pathogen, or that airborne transmission occurs in health care settings (Rhame, et al., 1984).

THE ROLE OF AIRBORNE SPREAD IN NOSOCOMIAL INFECTION

Finally, I wish to examine the relative contribution of airborne nosocomial infection to the overall problem of hospital infection. At the 1970 International Conference on Nosocomial Infection, held at CDC, Brachman reviewed the topic and concluded that although airborne spread certainly accounted for some nosocomial infections, the exact size of the piece was unknown (Brachman, 1971). He estimated, based largely on data available from the then infant National Nosocomial Infections Study, that airborne spread accounted for 10-20% of all *endemic* nosocomial infections, accounting for about a one percent incidence of infection among hospitalized patients.

In a 1980 review of airborne contagion, sponsored by the New York Academy of Sciences, Kundsin concluded, based largely on studies carried out at the Peter Bent Brigham hospital during the previous 20 years, that airborne spread in the operating theater accounted for 20-24% of all postoperative wound infections (Kundsin, 1980). Others doubted that the proportion was that high, and were skeptical of the importance of absolute levels of bacteria in operating room air, although instances of staphylococcal transmission from a surgeon to patients in the operating room have been thoroughly documented. The cooperative ultraviolet light study, although it did not show a dramatic effect of ultraviolet light in reducing rates of postoperative wound infection, did not directly evaluate possible routes of transmission of bacteria causing postoperative wound infection (National Research Council, 1964).

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

outbreaks of nosocomial infection in seven hospitals participating in an intensive surveillance study represented only about 2% of all patients with nosocomial infection (Haley, et al., 1985). Wenzel and his colleagues estimated that outbreaks accounted for 3.7% of nosocomial infections in a large university tertiary care referral center (Wenzel, et al., 1983). Among nosocomial outbreaks investigated by CDC from 1986-1990, over 67% were related to products, procedures, or devices (Jarvis, et al.,1991). Thus, airborne outbreaks of nosocomial infection have not been prominent, at least on a simple statistical basis.

Although reassuring, there have been some disquieting trends in the last decade. Particularly worrisome has been the resurgence of airborne nosocomial transmission of tuberculosis, a problem made all the more urgent by the multidrug-resistant nature of recent outbreaks. Outbreaks of airborne Legionellosis in hospitals continue to occur, as do airborne transmission of *Aspergillus* causing both endemic disease in certain special care units, and of construction-related outbreaks.

Thus, these concerns relate primarily to *epidemic* nosocomial infections., unanticipated, and unpredictable in occurrence. The only predictable thing about epidemic nosocomial infections is that they will continue to occur. Our challenge is to minimize this risk in hospitals, without laying another major incremental cost on our already precarious health care economy.

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A PERSPECTIVE OF VENTILATION FOR HEALTH CARE AND RELATED FACILITES

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INTRODUCTION

Perhaps it all started much earlier when Mrs. Neanderthal scolded her mate "The stench in this cave is making us sick!"

Certainly we can extract from biblical reports dating back 4000 years evidence of an acute need for ventilation—Noah's Ark. As early as 1500 BC, the ancient Egyptians identified silicate dust produced by the cutting of construction stone as a cause of respiratory disease (Lord 1986).

Windows for residences were decreed by Charles I of England as a defense against plague and other diseases. However, the outdoor air was often so foul as to be unsuitable for ventilation. The air in London was so bad that the year of 1357 was designated "The Year of the Great Stink." Even in 1661 London's air was characterized as "an impure and thick mist, accompanied with a fulginous and filthy vapour, corrupting the lungs and disordering the entire habits of the inhabitants' bodies."

Ben Franklin was considered deranged by his advocacy, contrary to prevailing medical opinion, of opening windows at night in order "to have a constant supply of fresh air in your bedchamber as a means of preserving health" (Franklin 1780).

The nineteenth century was the occasion of some significant research and hypothecation regarding the value of ventilation. Perhaps the most pertinent was that of J. S. Billings, an American physician, who in 1893 expounded on the connection between ventilation and the prevalence of pulmonary tuberculosis, and recommended 60 cubic feet per minute (cfm) of outdoor air per person for continuously occupied space, and that less than 30 cfm was inadequate. The American Society of Heating and Ventilation Engineers (an American Society of Heating, Refrigeration, and Air Conditioning Engineers predecessor society) with strong support from hygienists and physiologists, adopted the 30 cfm value as the minimum standard. This necessitated mechanical ventilation. The rate was subsequently considered excessive and we engineers were held responsible for overdesign of ventilation systems and wasting money (Klauss, et al., 1970).

Subsequent reevaluation of the health effects focused upon ventilation air quality and consideration of body odor as the controlling factor. This led to reductions in the recommended outdoor air ventilation rate and the substitutionary use of treated recirculated air.

Currently, ASHRAE Standard 62-1989, *Ventilation for Acceptable Air Quality* (ASHRAE, 1989) prescribes a minimum outdoor ventilation rate of 15 cfm per person with higher values for some occupancy classifications.

VENTILATION OF HEALTH FACILITIES

The ASHRAE Standard prescribes ventilation rates for hospitals and nursing and convalescent homes based upon cfm of outdoor air per person for five space classifications and one (autopsy) based on cfm per ft^2 of floor area. The sources for these values were the Guidelines (1983/1984) and the Minimum Requirements

(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

AIA values. Reasons for this are more obscure, but may reflect recognition that airborne surgical infections are more the consequence of air contamination in the micro-environment of the surgical procedure than the average concentration of viable particulates within the operating room. Total air change has bearing on the latter whereas room air distribution has more effect on the former.

Research Reports

Major emphasis on study and research into ventilation of medical care facilities has centered chiefly on the operating room. A number of studies reported upon total and outdoor air change rates, room air distribution techniques (both of supply and return air), quality of air filtration and anesthetics control. A study (Woods, et al., 1986) primarily directed toward energy and economic considerations recommended further investigation into control of the micro-environment.

Galson and Goddard (1968) proposed ventilation rates for most hospital spaces based on pre-established criteria of the maximum number of bacterial colonies per ft^3 in the room air. The rates proffered were frequently higher than applied in common practice by HVAC system designers. However, they were based on a rational, albeit stereotyped, analysis of the protection of occupants. With the exception of the risk to operating room personnel from anesthetic gases, the primary objective of ventilation study and design for medical facilities is protection of the patients, who are considered to be more vulnerable than the medical and support staff. The acknowledged risk of airborne infection by *M. tuberculosis* to medical-workers has altered the picture (Riley, Nardell, 1993).

Air Filtration

It is known that some microbial diseases can be transmitted through the indoor air (National Research Council 1987). Tuberculosis, influenza, staphylococcal infections, measles, mumps, the common cold and legionellosis are among those diseases identified (Stowlwijk, 1983). In addition, airborne fungi spores and fungi produced toxins are agents for hypersensitivity pneumonitis,

common allergies and more serious disease. Toxins produced by several species of fungus, such as *aspergillus versicolor*, are believed to be carcinogenic to humans (Morey, 1992).

Droplet nuclei, containing pathogenic organisms, can be carried and dispersed on air currents. The typical size range has been estimated at one to five microns (Kuehn, 1991), but extending both above and below this range, with the average size about three microns (Riley, Nardell, 1993). Particles of this size are respirable and can remain in suspension for days. Some require a large concentration to cause infection (Burge, 1990) whereas for TB a single mycobacterium deposited in the lungs is sufficient. Micro-organisms may also be transmitted through the air on host particles and even as single organisms (Kuehn, 1991).

The significance of the size of these infectious particles is that they are respirable yet most can be removed from the air by medium to high efficiency filters, thus reducing the probability of infection transmission. Typically fungi spores are similarly characterized in size between two and five microns. Their removal can reduce allergic response.

A standardized performance test procedure for predicting particulate removal efficiencies is still on the way. However, such efficiencies have been published for extended surface air filters by several sources (Ensor, et al., 1988). There is substantial agreement that filters with an ASHRAE dust spot efficiency of 90-95% (ASHRAE Standard 52.1-1992) will remove approximately 99% of particles in the one to five micron range. Even 60-65% medium efficiency filter as could be used in the HVAC system serving administrative and other non-medical space have a removal capability in the order of 75%. Bacterial removal efficiencies have been determined (Luciano, 1984) showing even more effective performance. HEPA filters, rated at 99.97% efficiency for 0.3 micron particles, offer little improvement in effectiveness over the 90-95% dust spot for the preponderance of pathogenic and allergenic particles. The higher efficiency HEPA filters are more costly and difficult to apply; consequently it is best to limit their use—especially in HVAC system— to highly critical situations.

Even well filtered recirculated air will contain noxious gases and vapors. The outdoor air ventilation component is necessary to dilute such contaminants unless gas adsorbers or oxidizers are employed. The outdoor air is not regarded as devoid of microorganisms and should be filtered along with recirculated air (Bernard, Cole, Claywell 1961). Providing substantial total air changes utilizing well-filtered supply air is, as Galson and Goddard (1968) proposed, an important factor in safeguarding both patients and staff.

Infection Risk

Health risks can be incurred from airborne pollutants generated within the inhabited areas of the facility by the occupants, processes or building materials. Pollutants may be introduced with the outdoor air through entrainment of effluent. They can also be produced within the ventilation systems themselves through the accumulations of biological material and organic nutrient. Toxic chemicals are occasionally unwittingly introduced as a biocide. Ventilation is countereffective if it introduces contaminants.

Dilution of contaminants generated within the spaces is secondary to source control as a health safeguard. Accordingly, ventilation is primarily intended to limit the concentration of those contaminants that cannot otherwise be controlled.

The ASHRAE ventilation standard includes an analysis procedure for predicting the concentration of space contaminants or determining the amount of air necessary to maintain concentration limits. However, its application in assessing health risk is sorely limited by lack of necessary situational data. At best such solutions are stereotyped and realistic predictions of results are going to be few. Even so the technique can prove useful in comparing system performance capabilities, such as the significance of total ventilation rates in operating rooms and isolation rooms.

Nardell, in an extension of earlier studies, evaluated the role of dilution ventilation as a control for the spread of tuberculosis demonstrating both its effectiveness and limitations (Nardell et al., 1991). If relevant situational parameters are known the incidence of cross infection is predictable.

Predictions are obtainable through the application of the Wells-Riley equation to evaluate risk from inhalation of infectious droplet nuclei based on steady state conditions, uniform distribution of droplet nuclei and dilution ventilation throughout the space.

$$C=S(1-e^{-Iqpt/Q})$$

The terms of this equation are:

- **C:** the number of new infections predicted
- **S:** the number of susceptible persons in the exposed environment.
- ***I:*** the number of infectors
- ***q:*** the number of "quanta" of infection added to the air per unit of time, quanta per hour(qph). The value is derived from data relative to a specific episode. It is then employed to predict the number of infections under altered circumstances, e.g., increased ventilation rate. The value is influenced by a number of factors such as the concentration of airborne droplet nuclei and the virulence of the microorganism genus and species. The range in values for various situations involving tuberculosis was reported by Nardell to be 1.25 to 250qph. In contrast, a measles case in a school produced an estimated 5480qph.
- ***p:*** the respiration rate (air sampled) per occupant,cfm.
- ***t:*** exposure time, hours.
- ***Q:*** the ventilation rate in cfm. Only outdoor air was considered as the means of dilution in the cited study.

It is perceived that the usefulness of this predictive technique extends beyond application to tuberculosis to other airborne diseases and response to allergenic organisms produced within the space. Application of the equation circumscribes the limits of effectiveness of reasonable ventilation rates in disease control. Beyond those limits, source control, irradiation, protective safeguards or other alternatives are going to be required for protection of exposed individuals.

The use of the Wells-Riley equation is extended a further step to enable performance comparisons of alternative dilution ventilation rates, air conditioning system performance and filter efficiencies. Simply stated, a rate of infection incidence (C_b) is established for a base ventilation rate produced by a selected HVAC system. This rate is equal to the outdoor air (presumed to be free of the infectious organisms) plus the recirculated air, discounted to account for the inefficiency of the filtration in removal of the infectious particle (droplet nuclei). A second rate of infection incidence (C) can be calculated for an alternative condition and then divided by the base rate to establish a performance or infection risk index ($I = C/C_b$).

This technique is submitted for more complete presentation at ASHRAE IAQ 93 Conference this autumn. A preview of the index application to a school classroom is shown on one of the visuals. Several observations of the classroom analysis can be transposed to health care situations. If a risk reduction in the order of 10 to 1 is desired, as might be to protect medical personnel from TB infection, dilution ventilation alone is not a solution. If the virility or concentration of the infectious agent is very high, source control (total isolation) or exposed person protection are the only apparent solutions.

Health Risk Effects of HVAC Systems

Intake locations: It seems axiomatic that intakes to air supply systems should be located away from the discharge of exhaust, combustion stacks and cooling towers. Yet this has proved deceptively difficult. Physical placement of mechanical equipment rooms in a manner that can predictably avoid entrainment of noxious materials is a challenge. Better to design the points of discharge of effluent away from intakes. The more flagrant violations of the separation principle often occur when supply or exhaust systems are added to existing buildings.

Factory built air conditioning units: Common features of such equipment, especially popular over the last two decades, that

increase the probability of the HVAC system becoming a source of contamination are:

- Inaccessible access to components.
- Flat condensate pans with side drain connections.
- Low efficiency filters.
- Mineral wool insulation exposed to the air stream.
- Inadequate provision for humidity control.

Better equipment is now becoming available as manufacturers react to indoor air quality concerns of their customers; but only through owner and designer recognition of its value will it be selected for our medical facilities.

Humidity control: Many older systems maintain humidity by recirculating water sprays. These are recognized amplifiers of bioaerosols and causes of heat transfer equipment depredation. Maintenance is so burdensome their use is usually terminated and wintertime humidification discontinued. Steam, free of boiler treatment chemicals and applied in a manner that will avoid wetting duct linings and downstream filters, is the preferred method of humidification.

Terminal humidifiers are sometimes installed in the individual supply air ducts fed by a common operating suite system. The range of design temperature and humidity conditions prescribed for operating rooms can be met by a single central humidifier control providing a moisture content of approximately 60 grains per pound of dry air. For specific operational procedures the temperature range may be stretched beyond normal design parameters. Even then the resultant relative humidity hardly represents a health risk or comfort compromise. Neglected maintenance of terminal humidifiers and their controls can, on the other hand, have serious consequences, which can be compounded if filters are placed downstream of the humidifiers. Wet (or dirty and wet) filters will reduce supply airflow—with the probability of creating a negative pressure within the operating room. For more reliable control and to avoid cross contamination between operating rooms, an individual air conditioning system for each is preferred, but this is frequently not feasible.

Space pressurization: A positive or negative space pressure relative to adjacent spaces is generally achieved by a deliberate imbalance of supply and exhaust airflows. The actual pressure differential created is extremely small and virtually unpredictable during design unless the room is of special sealed construction (ASHRAE 1991). Pressure relationships can be completely upset, even reversed, by door and window openings. Such relationships can also be compromised simply by depredations over time of the adjustments of airflow regulating devices throughout the system serving the critical rooms. Over reliance upon the protection provided by imbalance of airflows incurs a risk. Anterooms with independent air supply and/or exhaust as well as sealing of all openings are proven techniques. In existing hospitals, the need arises to convert ordinary patient rooms into isolation rooms (positive or negative). What then?

Variable Air Volume (VAV) Systems

VAV systems are one of the most popular concepts of air conditioning. Room temperature control is accomplished by regulating the supply airflow. Its use has been extended to patient care space, where formerly constant supply air flow with the room's temperature controlled by changing the supply air temperature had been considered essential. Accepting the energy use and cost benefits of VAV, usually involves compromise with indoor air quality objectives. Most VAV systems operating today are controlled in a manner that reduces outdoor airflow in proportion to the reduction in total system supply airflow. Moreover, if exhaust airflow is constant, a shift from positive to negative pressure may occur in individual spaces or the entire building causing infiltration of potentially contaminated air.

Considerations for the Future

Shifting populations will continue to create a need for new medical facilities. However, with the pressure to contain medical costs, there is likely to be increased emphasis on the more effective use of those now existing. Many of today's air conditioning systems are old, less able to perform as they once could. At their best they would hardly

meet current indoor air quality and medical treatment criteria. Upgrading or replacement must occur. Replacement concepts for desired improvement are not always easy or obvious.

Reductions in health risk to building occupants from airborne infection are likely to involve improved source control through isolation and containment, elimination of known reservoir and amplifiers of microorganisms, and better ventilation techniques. Weakness in the housekeeping, maintenance and operation of HVAC equipment is a reality, but many past design and construction practices have made these functions hard to accomplish.

Improved design for better component access has been mentioned. Upgrading filters for higher efficiency can often be accomplished through new filter cell designs at favorable cost and reduced maintenance. Dirt collecting room units can be replaced with more cleanable designs (now coming on the market) or, better yet, with all air systems. Ultra low temperature all-air systems take less space and may even cost-justify replacement through operational savings. Isolation of infected patients may be facilitated by application of displacement ventilation principles coupled with local exhaust near the patient's head as a means of source control. The use of air curtains at patient room doorways offers the opportunity for improved isolation where anterooms are impracticable. The expanded use of high total air change rate room ventilating systems now being employed for protection of immuno-suppressed or -compromised patients and ultra violet irradiation or both, may also be applied to protect staff and visitors.

Twin duct air system concepts combining the desirable features of VAV and constant volume air conditioning can augment or replace existing VAV systems to upgrade indoor air quality and comfort control.

It is hoped that this limited list of suggestions may stimulate the discussions of the workshops toward the achievement of the goals of the conference.

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PLENARY ADDRESSES

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 5.9×10^{-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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SOURCE CHARACTERIZATION AND CONTROL

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INTRODUCTION

With the reemergence of tuberculosis as a major public health problem in the United States, the control of the transmission of airborne infections in health care facilities and other workplaces has received renewed attention. Not surprisingly, after years of neglect, we find that our scientific knowledge base in this area is very weak, and that control programs in many health care facilities are less than ideal. As a result of this ignorance, our attempts to improve our procedures and guidelines have been largely based on extrapolation from other areas rather than on data from direct studies of this problem. This extrapolation has lead to controversy and concerns about the soundness of these recommendations.

One source of this problem in applying principles of occupational health prevention to the control of airborne transmission is the nature of the exposure being controlled. Most commonly in occupational health, we try to control an exposure resulting from a work-related process such as manufacturing a chemical or removing insulation from a building. However, in the case of airborne infections, the major source of exposure (with some

exceptions to be discussed below) is a person, usually a patient at a health care facility. In contrast to an industrial source which is usually relatively fixed and constant, the source of airborne infections is very dynamic—he or she moves around and usually resists staying in one place or one position for very long. Moreover, the process that produces the "airborne infection" is also very dynamic. Levels of production appear to increase and decrease with little predictability, hardly a desired characteristic of a manufacturing process.

Despite this unpredictable nature, we have been relatively successful in the past at controlling exposure to airborne infections in health care facilities. I believe that most of our success in this area does not result from the usual techniques used in occupational health such as exhaust ventilation, personal protective equipment, etc. Rather, our colleagues in communicable disease and infection control have achieved this control by identifying potential sources of infection and isolating this potential source. This source identification and control has been a major accomplishment and should be recognized as the key step in controlling transmission in health care facilities. Data from the major recent hospital outbreaks illustrate the tragic results when this process breaks down.

Now, there is much that is known (and unknown) about identifying infectious patients and other sources of airborne infectious diseases. In summarizing that information for this paper, I have tried to follow the plan for this meeting of following traditional occupational health control approaches. While this may detract from easily summarizing some of this literature (particularly the clinical aspects), I believe that this translation into "occupational health" terminology will provide better integration with the rest of this conference and recommendations. I also have not tried to rigidly separate our scientific knowledge about these sources from the current status of control programs. The latter obviously depends on the former, and an artificial separation between the two is confusing.

CURRENT KNOWLEDGE: AIRBORNE INFECTIONS IN HEALTH CARE AND RELATED FACILITIES

Diseases of Interest

There are many diseases which pose a potential risk for airborne spread in health care facilities. Obviously, almost any illness that is communicable via the airborne route may be transmitted to workers in a health care facility. The more important diseases include tuberculosis, varicella, rubella, rubeola, influenza, and aspergillosis. For the most part, these fall into two categories. The first category includes all illnesses whose major source is an infected patient in the facility. Given the current importance of tuberculosis, most of the discussion will focus on that illness. As tuberculosis is a chronic infection, the control of its source is much more complicated than for acute infections. Other diseases will be mentioned as examples, but many of the same research and control considerations also apply to those diseases. For the second category, aspergilla will be discussed in relation to environmental contamination and control. Although not important as a cause of illness in workers in health care facilities, aspergillosis is important as a cause of illness in susceptible patients, and the transmission of the disease illustrates a disease where other environmental sources are the major source of transmission.

The control of the spread of these diseases in health care facilities is also related to the prevention of transmission from patient to patient and from staff to patient. Many of our current control programs are directed at all three types of transmission. Although this document focuses on transmission from patient to health care worker, these other types of transmission are critical to many of our control procedures.

Patient as Source of Airborne Infection

The major source for the transmission of airborne infections in health care and related facilities is from infected patients. The bacteria or virus is exhaled as respirable droplet nuclei when the

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).

Evaluating the Infectivity of Patients

Determining whether or not a patient is infectious is obviously a key factor for identifying a potential source of transmission in a health care facility. However, determining this may be quite difficult due to the limitations of the currently available techniques. Usually, these tests assess whether infectious microbes are present in the sputum or other bodily fluid from the patient. Other tests focus on the immune response of the patient to the infection. These tests evaluate whether or not a patient is infectious by determining the stage of the patient's infection.

The most immediate method for evaluating potential transmission of airborne infection would be to evaluate the patient's sputum for the presence of such organisms. This procedure has traditionally been used for tuberculosis and is a critical step for identifying and monitoring the course of that disease (Des-Prez and Goodwin, 1985). Sputum is collected, placed on a slide and stained, and the slide examined under a microscope. Patients who are smear positive are known to be more infectious than those who are not and conversion to smear negative is used as a marker for response to therapy and considering the patient as no longer infectious (Rouillon et al., 1976, Noble, 1981). Recent outbreaks indicate that among culture positive patients, those that are also smear positive are much more infectious than those who are not (Beck-Sague et al., 1992).

Proper collection of a sputum sample is critical for this procedure, and procedures to induce a cough are often used. Due to the unpredictable production of infectious sputum in patients with TB, at least three smears are usually used. For the most part, this technique is used only for tuberculosis, not for the other illnesses transmitted by airborne route in health care facilities.

Another evaluation of infectivity is the utilization of cultures to grow and identify the microorganism. This can be done for tuberculosis and for some of the other infectious diseases in this

category. However, results often take several days or longer to complete, and antibiotic sensitivities (to identify drug resistant strains) may take even longer to complete. Although not as helpful in the immediate identification of the infected patient, cultures are critical to confirming the infection, identifying the specific type of microorganism, and determining sensitivity to treatment (Des-Prez and Goodwin, 1985).

Immune response may also be utilized in determining whether or not a person is infected. This can be done either through blood testing or skin testing. However, such testing is usually not helpful for determining the presence of an acute infection; presence or absence of an immune response must be interpreted with clinical information about the patient's course, etc. and such responses are usually delayed. Nevertheless, such testing could be useful particularly with better techniques to identify acute infections.

Other Patient-Related Sources of Airborne Infections

While the major source for the transmission of airborne infections in health care facilities is from droplet nuclei exhaled from infected patients, there are some other patient-related sources. These sources are usually responsible for only occasional cases but can at times be responsible for local epidemics or be a significant source of risk for certain categories of health care workers.

For tuberculosis, one significant source may be an open (usually draining) wound or abscess (Hutton et al., 1990). Manipulation of the wound or abscess by a health care worker (e.g.,debridement) can cause microorganisms in the wound to become airborne.

A more common source of exposure occurs from medical procedures that may induce cough in infected patients or involve contact with the patient's respiratory tract. Transmission of tuberculosis has been reported with procedures involving close contact with the patient's respiratory tract such as bronchoscopy and intubation (Catanzaro, 1982, Ehrenkranz and Kicklighter, 1972, Haley et al., 1989). Procedures that induce sputum

production may also lead to the transmission of tuberculosis (Beck-Sague et al.,1992, CDC, 1989). The latter pose a risk for not only people in the room during the procedure but also for people entering the room at a later time (prior to clearance of the droplet nuclei).

Autopsies on infected patients present an opportunity for exposure in the handling and manipulation of infected tissue. Cases of tuberculosis have been reported in these settings (Kantor et al., 1988, Lundgren et al., 1987).

Environmental Sources of Airborne Infections

Although many microorganisms capable of causing airborne infections may remain viable for a long period of time after being deposited on surfaces, they usually must become airborne in order to infect patients or employees. Therefore, for most airborne infections, surface contamination plays a minor role in the transmission of the disease. A more important role for surface contamination is illustrated by aspergillosis. Aspergilla spores in the environment may be an important source of infection in a health care facility.

For tuberculosis, studies of conversion rates in hospitals have found that surface contamination plays little role in the development of infection (Rubin, 1991). However, tubercle bacilli may persist for long periods of time on surfaces. There have been case reports of people infected from contaminated bronchoscopes and from contaminated needles (Rubin,1991). However, such reports are rare, and environmental surface contamination does not appear to be a common route of infection.

On the other hand, environmental contamination is an important source of exposure for aspergilla. Nosocomial outbreaks have been associated with aspergilla exposure from a breakdown in a hospital ventilation system or from construction taking place in or near the health care facility (Arnow et al., 1991, Rhame, 1991). Declines in endemic nosocomial infection rates have followed efforts to reduce spore counts by ventilation changes, filters, and

other measures (Arnow et al., 1991). Nearly all cases of aspergillosis occur in significantly immunocompromised patients (e.g., bone marrow transplant patients). Hence while important as a nosocomial infection for hospital patients, aspergillosis has not been commonly reported in health care workers as a result of work-related exposures. However, it does illustrate the potential problems of ventilation systems contributing as a source for airborne transmission of infectious agents.

CURRENT CONTROL PROGRAMS

Source Identification

Prompt identification of infected individuals is the cornerstone for the prevention of the transmission of airborne infections in health care facilities (CDC, 1990). Once cases or suspected cases are identified, appropriate precautionary steps and procedures can then be initiated (isolation, etc.). This identification is largely dependent on clinical signs and symptoms. Knowledge of the local epidemiology of the disease can be important (who is likely to be infected) as well as the usual presentation for the illness. For example, tuberculosis patients with HIV infection often present clinical signs and symptoms different from "classical" tuberculosis. Health care facility workers involved in admitting patients need to recognize these "different" presentations.

Laboratory testing is critical for the confirmation of the clinical suspicion. As discussed above for tuberculosis, examination of sputum smears is a key procedure for early and quick diagnosis. The ready availability of this procedure is necessary for assisting with prompt diagnosis. Long delays can lead to inappropriate isolation of hospitalized patients or to infected patients not being appropriately isolated. The limited sensitivity of this test also limits its utility for rapidly identifying infected patients. AFB cultures, while more sensitive, take much longer to complete limiting their use for immediate decision making.

Other laboratory tests are also useful. For example, chest X-rays are critical for the diagnosis of tuberculosis. Tests of immune reaction (blood or skin tests) can be helpful in the diagnosis of these conditions.

Confirmation that a patient is no longer infectious is also critical for determining whether isolation procedures can be discontinued, whether a patient can be discharged, etc. As discussed above, this determination may be difficult for patients with tuberculosis because of the variable clinical course of the illness and the limited sensitivity of sputum smears for detecting infected individuals. The increasing incidence of drug resistant strains further complicates this determination.

Source Control Methods

Many of the source control methods used for airborne infections are procedural rather than the mechanical methods used in the control of industrial exposures. One key control method is for infectious patients to cover their mouths when coughing. Since coughing is a major source of infectious nuclei, this procedure can markedly reduce the potential for transmission of infection to other individuals. The use of a respirator is also recommended when an infectious patient is outside of an isolation area (CDC, 1990).

Keeping an infected patient in an isolation room as much as possible is also important as a method of "source control." Procedures to limit the need for them to go to other areas of the health care facility and to minimize the time spent in those areas are necessary.

Compliance with isolation restrictions can vary. Patients may need to be isolated for long periods of time. Many hospitals have made efforts to improve this restricted environment by providing televisions, VCRs, etc.

Mechanical means of infection control are important for procedures that may increase the production of airborne nuclei (e.g., sputum induction) or that lead to increased exposure for health care facility employees (e.g., bronchoscopy). Enclosed booths

are the preferred procedure for sputum induction and aerosolized pentamidine administration. These booths need to be properly exhausted to ensure that airborne nuclei are not introduced into the room during or after the procedure. Exposures during bronchoscopy can be controlled with local exhaust systems although these systems have not been as widely implemented as the sputum induction booths.

Immunization and Screening

One other form of control for airborne transmission is to immunize the health care worker to prevent them from becoming infected. For example, for rubella, this is the major method of control in a health care facility to prevent infection in health care workers, and such immunization is mandated in many states. For tuberculosis, there is considerable uncertainty about the efficacy and indications for the use of BCG.

Another procedure is to screen health care workers for evidence of infection. If they develop evidence of an infection, they can then be treated with prophylactic medication. This method has been widely used for tuberculosis (CDC, 1990). Appropriate skin testing procedures need to be followed. There are also difficulties with prophylactic treatment including poor compliance and adverse reactions to the medications.

MAJOR ISSUES, PROBLEMS, OR RESEARCH GAPS

Based on this review of our current state of knowledge, there are several major issues related to the identification and control of sources of airborne transmission of tuberculosis in health care facilities. Two major issues critical to control will not be discussed as they are beyond the scope of this meeting. Obviously, better control of the community epidemic of tuberculosis, rubeola, etc. will help to control the risk in health care facilities. Secondly, the development of better treatments for these conditions would also greatly assist in the control of transmission in health care facilities.

Better Methods for the Identification of Infectious Patients

The prompt and accurate identification of infectious patients is critical for the prevention of the transmission of airborne infections in health care facilities. Current methods are not sensitive, may not identify early stages of infection, or may take too long to process to be useful in many situations. Current research is developing better methods. For example, for tuberculosis, more sensitive and faster techniques for detecting tubercle bacilli on smears and cultures are currently being developed and introduced (Wilson et al., 1993,Abe et al., 1992, Crawford et al., 1989).

After treatment has started, it is also important to know when a patient is no longer infectious. This is especially important for tuberculosis where long term treatment is required. Although this determination may be similar to identifying an infectious patient, different considerations of sensitivity and specificity may apply, and a rapid test may not be as critical.

Methods for Quantitating Infectiousness

Currently, all patients with infections capable of airborne transmission are essentially handled the same in terms of judging their potential infectiousness. There are some exceptions to this approach based on clinical indications. However, currently available methods do not provide a good way of assessing differences in infectiousness despite evidence that there is considerable variability in infectiousness between different patients with similar clinical findings. A method of determining the production of infectious nuclei by a patient would be extremely helpful for determining the type or degree of isolation for a patient and for decisions on respirator use and other administrative control measures.

Ideally, a method needs to be developed to measure air levels of infectious particles. With polymerase chain reaction and other very sensitive (and specific) techniques, the development of such a method should be feasible (Wilson et al., 1993). Even if such a

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

what factors contribute to this infection rate. Better clinical follow-up of infected patients is currently underway, and it is important that this type of information be obtained from this follow-up.

Implementation of Better Programs to Identify Infectious Patients

From the experience in New York and other areas, it is clear that much needs to be done to improve the identification of TB infected patients in health care facilities. This includes better availability of diagnostic services and better protocols for identifying potentially infectious patients. For settings such as emergency rooms, this can be done through protocols for the identification of potentially infected patients and then the implementation of special procedures for isolating and testing these patients. This approach needs to be extended to other types of facilities where care may be provided for "high risk" groups (extended care facilities, home health care, homeless shelters, etc.)

Development of Immunizations

Immunization of susceptible individuals is a key method for protecting employees from the transmission of some airborne infections (e.g., rubella). The development of effective immunization methods for other diseases could be the most effective method for preventing transmission to employees in health care facilities. Health care workers in some countries are routinely given BCG to protect against tuberculosis. However, the efficacy of BCG for the protection of employees from TB transmission is unclear (Lugosi, 1992, Collins, 1993). This needs to be reevalauted and better methods developed.

Susceptibility

Immunocompromised individuals are more likely to be infected from exposure to infectious droplet nuclei (CDC, 1990). This has been clearly documented in the incidents involving the nosocomial

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

these must meet a number of criteria. They must provide adequate capture without interfering with the procedure. Placement during the procedure is also critical. Better systems for these procedures must be designed and implemented.

Another area where special "source" controls may be useful involves the transport of infectious patients from isolation rooms to other areas of the health care facility for diagnostic procedures, etc. Current policies recommend the use of a respirator by the patient. Special tents or hoods to cover the wheelchair or stretcher might be useful, providing that adequate filtering was used and patient comfort provided.

Disinfection

Although not the major mechanism for the spread of most airborne infections, surface contamination may account for some cases. A better understanding of approaches to disinfection may help to prevent unnecessary transmission of these infections and possibly lead to new control measures. For example, one method of disinfection for tuberculosis, ultraviolet light is now used for general room disinfection. Perhaps other disinfectants could be used in similar ways.

RESEARCH AND CONTROL PROGRAM NEEDS

Based on the issues discussed above, several priorities for research and control programs can be identified:

Research Needs

- Research is needed to develop better methods for diagnosing infections capable of airborne transmission in health care and similar facilities. This need is particularly critical for tuberculosis where long delays between specimen collection and culture results may significantly delay the identification of patients. These methods need to be more sensitive and more rapid

than current methods. A rapid test to identify potentially infectious patients would be very useful as well as quicker methods for identifying drug resistant organisms.

- Research is also needed to develop a better method for quantifying the infectiousness of an infected patient. Patients differ in their infectiousness, and current assessment of this infectiousness depends on general clinical criteria. A method to directly measure infectiousness would be very useful. The development of a method to measure air concentrations of infectious droplet nuclei should be feasible using techniques such as polymerase chain reactions (PCR). Even if this method was only available for research purposes, valuable information about the efficacy of isolation procedures, ventilation, etc. could be obtained.

- Although current methodology has significant limitations in identifying infectious patients, tracing the source of an infection, etc., large numbers of workers in health care and related facilities are being exposed to tuberculosis and other airborne infections. Follow-up studies of these workers need to be undertaken in order to better understand the sources of airborne infections and the efficacy of current control procedures. These studies need to be extended to include workers in other settings including home health care, drug and alcohol treatment centers, homeless shelters, and other types of workplaces where workers may be exposed to airborne infections.

- The use of immunizations is an important method for protecting health care workers from certain airborne infections. For other types of infections, methods are not available or there is uncertainty about their effectiveness. Better immunizations need to be developed especially for tuberculosis.

- Protecting health care personnel during special procedures such as sputum induction and bronchoscopy involves the utilization of special ventilation booths and local exhaust systems. These control methods need to be evaluated and better control methods developed for these procedures.

- Maintaining infectious patients in isolation for long periods of time will be difficult. The evaluation of factors related to compliance and methods to improve compliance with isolation procedures would be very helpful.

- Although some organisms capable of airborne transmission may remain viable for long periods of time on surfaces, this is not an important source of transmission except for aspergillosis (and then only by the microbe becoming airborne). However, a better understanding of the possible role of this potential source of infection as well as methods of disinfection would be helpful.

- Health care workers with impaired immune systems are more susceptible to airborne infections. A better understanding of the indicators of susceptibility would be useful for their personal decision making regarding the use of protective measures, etc.

Control Program Needs

- Health care and related facilities need to develop and implement programs for the rapid identification of patients who may be infectious. These programs need to include procedures for expediting diagnostic testing on these individuals and must include the ready availability of screening tests such as AFB smears. Regional programs may be needed to expedite more complicated tests such as drug susceptibility testing.

- Surveillance systems must be in place through local and state health departments to facilitate the identification of patients known to be infected by the appropriate sharing of this information with health care providers.

- Special procedures such as bronchoscopy and sputum induction must only be carried out in areas with proper local exhaust or other ventilation.

- Training is critical both for the education of patients about ways that they can limit the transmission of their disease as well as for health care workers on ways that they can reduce their risks.

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BUILDING DESIGNS

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WHERE WE ARE—BACKGROUND

The context of this workshop is complex and of grave concern to those involved in health care:

- A growing number of newly diagnosed cases of tuberculosis (TB) in the general population of the United States.
- 32 recent deaths due to multidrug-resistant (MDR) TB—many of which were the result of nosocomial infections (CDC, 1991).
- And the fact that 23 % of the New York State inmate population has tested positively for TB (Greifinger, 1992).

While inner city hospitals have faced the growing numbers of TB patients, the majority of the nation's health care facilities have not. Focus throughout the country has rested largely on developing the appropriate responses to acquired immuno-deficiency syndrome (AIDS) and other major public health issues. These include continuing efforts to combat and treat cancer, substance abuse, infant mortality and cardiovascular disease. Coupled with increased efforts to control capital and operating expenditures for health care and the subsequent move toward health care reform, little attention has been left for an affliction largely unknown by

many Americans other than a threat from times past. In addition, past efforts to slow or limit increases in health care expenditures, such as construction moratoria and certificate of need processes, have increased the extent of our aging health care infrastructure. And, because of changing health care needs, delivery patterns and funding, TB sanitoria have long been abandoned as have many of the nation's state-run psychiatric centers. Newer facilities with energy efficient mechanical systems have allowed potentially dangerous concentrations of TB through the use of recirculated air (Iseman, 1992).

The public awareness of the return of tuberculosis as a major public health threat has been so relatively recent and limited that very little attention has been paid to building design as a specific response. An indicator of the relative concern about TB and its impact on facilities can be seen in a review of recent health care industry journals and publications such as *Health Facilities Management*, *Modern Health Care*, and *Hospitals*. Very few feature articles on facilities dealing with TB have appeared, with the most notable article appearing in *Health Facilities Management* which emphasized ventilation requirements and options (Neill, 1992). It is the opinion of the writer that only two programs out of approximately one hundred will address any TB-related issues at the upcoming International Planning, Design and Construction Symposium sponsored by American Society of Hospital Engineers (ASHE).

Within general acute care institutions such as hospitals and medical centers, the majority of attention regarding the isolation needs of patients have dealt with AIDS patients and others with immunosuppression and their need to be protected from opportunistic disease. Thus, in may facilities, the emphasis has been on protective isolation. In general, pediatric facilities have been more concerned about infectious isolation and limiting nosocomial infections.

Thus the perceived need for infectious isolation facilities has not been high. In fact, it is the writer's observation that many facilities regard the need for full-blown protective and infectious isolation

rooms with anterooms to be largely unnecessary especially in light of the move toward greater percentages of, if not total, private patient accommodation. Only in 1992 did the American Hospital Association (AHA) issue a member briefing specifically focused on TB (Technical Panel on Infections Within Hospitals, 1992).

Our charge is to develop a research agenda which will support the protection of health care workers from TB. The risk has increased because of, according to one team, various cough-generating procedures used with AIDS patients (Nardell, 1990). In preventing the airborne transmission of TB, the greatest impact is generally on the patient. And many of the traditional measures to combat or contain TB appear to ignore concerns about patient autonomy, ranging from involvement in medical decision-making and limited inpatient stays to control over one's individual environment in the health care facility. One of our challenges, or that of those who take up the implementation of our agenda, is to address public health needs effectively without totally losing sight of individual patient needs.

Many patients, after initial diagnosis, do not require inpatient hospitalization for medical management (Stead, 1992, Berkow and Fletcher, eds.,1987). However, many others do. They include those with conditions requiring other supportive measures not possible on an outpatient basis and those with multidrug-resistant TB. There are now also increasing numbers of patients who are not compliant in terms of continuing medication and observing proper infection control precautions. Recommendations have been made to consider involuntary confinement for non-compliant patients during the chronic phase of their illness—not just during the time when they are infectious (Rothman, 1992). It is because of these patients that the concerns for other patients and staff arise. These patients already have and will continue to tax the available isolation facilities. The lack of adequate numbers of acid-fast bacilli (AFB) isolation rooms was clearly implicated in the recent outbreaks of nosocomial TB (CDC, 1991).

In response to the Centers for Disease Control's (CDC) published guidelines for control of TB transmission (CDC, 1990), it appears that the primary focus of building design in this area should be isolation facilities within health care institutions. CDC recommendations for the medical management of infectious patients requiring hospitalization include the use of AFB isolation precautions (CDC, 1991). CDC indicates that this includes use of isolation rooms with requirements which mirror those listed in the American Institute of Architects (AIA) *Guidelines* (AIA, Committee on Architecture for Health, 1993).

The AIA's *Guidelines* document does not specifically address TB as an infectious agent but does provide space and engineering requirements for infectious isolation rooms. These requirements include the use of a private room with negative air pressure in relation to surrounding areas and a minimum of six air changes per hour. All air is to be exhausted directly to the outside in such a way that it will not become pulled into supply intake vents for any area of the facility. *Guidelines* also indicates the need for an anteroom of 20 net square feet directly adjoining the intensive care isolation room and serving as a buffer between the isolation room and the general corridor (AIA, Committee on Architecture for Health, 1993).

Additional CDC recommendations indicate the need for the use of disposable particulate respirators by staff entering the isolation room (CDC, 1991). The use of surgical masks by the patient when he or she is required to leave the isolation room while still infectious has been instituted in at least one New York City hospital (Pearson et al., 1992).

While cohorting of patients and sharing of anterooms is not acceptable because of potential superinfection of MDR TB, one group feels that private rooms with positive air pressure can be used with window exhaust fans (Lutwick et al., 1992).

While the major facility response at the end of the last century and earlier in this century was the sanatorium (Dubos and Dubos, 1992), concerns about staffing, duplication of services and availability of specialized diagnostic and treatment equipment have argued against single-disease facilities as a current-day solution (Rothman DJ, 1992, Rothman SM, 1992). Thus, the continued development of hospital- and medical center-based inpatient isolation facilities is advised. However, these need to accommodate both acute care patients as well as intensive care patients. In addition, prison infirmaries should include AFB isolation rooms (CDC, 1992d, Glaser and Greifinger, 1993) and diagnostic services such as x-ray (Skolnick, 1992).

Issues arise regarding the best kind of facility or location of care for the patient who is not or is no longer acutely ill but is still infectious and requires on-going medication. Some patients are able to manage the appropriate precautions to avoid transmission to family members and others. Other patients, by virtue of their medical condition or lifestyle, are not able to manage on their own and require a supportive environment which may include personal care assistance (Torres et al., 1990). Such services are sometimes available in outreach facilities including shelters or nursing facilities. CDC recommendations have included establishment of special housing-treatment centers for the homeless with TB (CDC, 1992c).

WHERE WE ARE GOING—RESEARCH AGENDA

As indicated above, the nation has a shortage of appropriate isolation facilities. In some facilities, where they exist, their mechanical systems have not been properly maintained or balanced so that their effectiveness is limited.

Consideration should be given to the development of specific planning and design guidelines, including but not limited to:

Health Planning

- Developing methodologies to calculate the number of inpatient acute and intensive care infectious isolation rooms for a given service population.
- Developing methodologies to identify the type and number of hospital-based ancillary services needed to support that population including diagnostic and treatment facilities such as lab, x-ray, surgery, etc.
- Developing methodologies to identify alternative care delivery sites such as schools, shelters, residential treatment centers, etc. and their capacity based on the needs of the service population.

Design and Construction—Inpatient Facilities

- Identifying the criteria and parameters for determining the feasibility of renovation in existing construction to provide appropriate isolation capacity—both for acute and intensive care including:
  1. Staffing.
  2. Construction cost.
  3. Construction duration.
  4. Disruption to other ongoing facility operations.
  5. Access to other essential support and services.
- Developing specific programming guidelines for isolation facilities including the room itself, the anteroom and associated bathing and toileting facilities.
- Identifying the specific furniture, furnishings and equipment elements required in an isolation room.
- Confirming the necessity of providing an anteroom:
  1. As an airlock.
  2. As a work and storage area in which to practice infection control measures, etc.
- Developing specific construction standards for doors, windows and seals based on the results of the panel investigating ventilation design.

- Identifying specific design elements to be included in the anteroom, e.g., interlocks on the doors to prevent accidental airflow between patient room and corridor.
- Identifying specific design elements to be included in the patient room itself to accommodate ultraviolet (UV) light installations and/or high efficiency particle air (HEPA) filtration—should their efficacy be confirmed.
- Identifying the appropriate design to accommodate access to and from booths for use by patients required to perform sputum induction, etc.
- Identifying the different needs, if any, of the short-term versus long-term patient.

Design and Construction—Outpatient and/or Diagnostic and Treatment Facilities

The above suggested areas of investigation centered on a hospital or medical center's inpatient nursing units. In addition, consideration should be given to identifying the extent of isolation facilities needed in other settings such as residential TB treatment facilities (Brudney and Dobkin, 1991) and various diagnostic and treatment services.

- The emergency department
- Intensive care units
- HIV clinics and related services such as:
  1. Pentamidine administration clinics.
  2. Outpatient intravenous treatment areas (Abrutyn, 1992).

Specifically, within the emergency department, the triage and intake functions should be addressed in terms of the facilities required to accommodate the interaction required between patient and health care worker to determine the patient's potential for active TB. Given Joint Commission on Accreditation of Health care Organizations (JCAHO) requirements that the patient's first encounter is with triage staff, the physical setting of this interaction needs to be examined in light of protection of the staff as well as encouraging patient safety, confidence and comfort.

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

of providing diversion and stimulation must be included, such as TV, interactive computers, etc. An additional area of investigation should be the identification of minimum levels of recreational facilities, etc. and means of allowing interaction with family members and friends without risk to either visitor or patient.

Alternative Sites

Consideration should be given to use of other facility types as alternatives to hospital-based care. Even though it was stated earlier that single-disease facilities are not recommended, in certain urban or metropolitan areas existing building stock may not be able to accommodate the growing need for appropriate facilities—especially in areas with high percentages of homeless persons who may be subject to involuntary confinement (Brudney and Dobkin, 1991). Consideration may also be given to regionalization of care for TB patients at risk for MDR TB (Beck-Sague et al., 1991). In such circumstances, criteria should be developed for the adaptation of other building types including:

- Schools.
- Psychiatric centers.
- Unused military installations.

Criteria should include:

- Access to the facility from the community.
- Staffing availability and cost.
- Access to diagnostic and treatment services.

Whatever national or other jurisdictional health planning mechanisms may come out of the Clinton administration's reform program, CDC at a minimum should promulgate the results of the health planning analyses indicated above. In this same context, the Health Care Financing Administration (HCFA) must address financing of renovations and/or new construction to meet the needs of additional isolation facilities.

When specific facility design and construction standards are developed, they should be promulgated by whatever entity will be

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)

Evaluation should be performed by CDC and JCAHO, with specific emphasis on health care institutions. Local public health entities with assistance from CDC and NIOSH should evaluate other settings of care and risk such as schools, shelters, etc.

HOW WE GET THERE—IMPLEMENTATION

The areas of proposed research should be allocated to specific groups based on expertise and ability to accomplish the research task in appropriate time frames. If possible, a consensus-building model should be used. Based on personal knowledge, the writer recommends an approach similar to that taken in the preparation of the *Guidelines*.

It should be noted that the inclusion of certain elements is dependent upon the research activities coming under the jurisdiction of other panels. For example, the use of UV lights and HEPA filtration as devices in patient rooms is predicated on confirmation of their efficacy and practicality of use. The use of booths for containment of contamination generated during sputum production, aerosol pentamidine administration and bronchoscopy is predicated on outcomes by the source control panel and possibly the aerosol characterization panel. Therefore, it is recommended that an overall map or critical path be developed of the recommended tasks identified by each panel and that they be sequenced as needed.

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VENTILATION DESIGNS

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HISTORY

On October 22, 1947, rules required under Title 42 Chapter 1 — Public Health Service, Federal Security Agency, Part 53 Grants for Survey, Planning and Construction of Hospitals were published in the Federal Register. In this rule, specific requirements for the Ventilation of General Hospitals, Mental and Psychiatric Hospitals, and Tuberculosis Hospitals were described. Among these were the following:

> *Ventilation.* Rooms which do not have outside windows and which are used by hospital personnel, such as Utility rooms, Toilets, Bed pan rooms, and Baths, and Sterilizer rooms, shall be provided with forced or suitable ventilation to change the air at least once every six minutes.

> Kitchens, morgues and laundries which are located inside the hospital building shall be ventilated by exhaust systems which will discharge the air above the main roof or 50'-0" from any window. The ventilation of these spaces shall comply with the State or Local Codes but if no code governs, the air in the work spaces shall be exhausted at least once every six minutes with the greater part of the air being taken from the flat work ironer and ranges. Rooms used for the storage of inflammable material shall be ventilated to the outside air with intake and discharge ducts.
>
> The operating and delivery rooms shall be provided with a supply ventilating system with heaters and humidifiers which will change the air at least eight times per hour by supplying fresh filtered air humidified to prevent static. No recirculation will be permitted. The air shall be removed from these rooms by forced system of exhaust. The sterilizing rooms adjoining these rooms shall be furnished with an exhaust ventilating system.

The significance of this rule was considerable in that compliance was required in order to obtain Federal Grant money to build these health care facilities. At least one state department of health continues to use some of the language in this rule today. Notice that the interior rooms of these buildings were required to have 10 air changes per hour (ACH) and that the operating rooms only eight ACH of outside air. The beginnings of pressure relationships were also spelled out regarding the OR and sterilizer rooms.

With this rule, there began a systematic attempt to standardize the performance of health care facility ventilation systems across the country. The idea of infectious disease passing through the air from one person to one or more other people did not begin in 1947.

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

design guidelines. This chapter is presently under revisions by the Healthcare Facilities Subcommittee of Technical Committee 9.8 Large Building Air Conditioning Applications and is to be published in the *1995 Applications Handbook*. The history of this chapter shows the evolution of the industry and of some of the politics which shape that evolution.

ASHRAE AND HEALTH CARE FACILITY DESIGN GUIDELINES

In the 1959 ASHRAE Guide Chapter 8 was entitled "Air Conditioning in the Prevention and Treatment of Disease." The opening paragraphs described the effects of knowledge gained from World War II regarding the importance of the control of airborne infection. It also described the benefits of air conditioning in aiding the convalescence of patients. Another interesting topic in those opening remarks was the unique air conditioning problems in civil defense shelters, a topic which later moved into a separate section of the Guide book. The text describes the effects of a surface or subsurface blast of about 20 kilotons. Given the politics of the time it is little wonder how such a topic could find its way into a discussion about health care facilities.

Other topics in the 1959 Guide Chapter 8 included:

> Sanitary Ventilation, Control of Airborne Infection, Value of Air Cooling under Tropical Conditions, Treatment of Disease, Operating Rooms (including a subheading on reducing explosion hazard), Nurseries for Premature Infants, Fever Therapy, Cold Therapy, Allergic Disorders, Oxygen Therapy, and General Hospital Air Conditioning.

The *1962 Guide and Data Book* contained a Chapter 28 entitled "Hospital Air Conditioning." Topics included:

> The Infection Problem, Air Quality, Air Cleaning, Air Movement, Zoning, Air Conditioning Systems, Design Criteria.

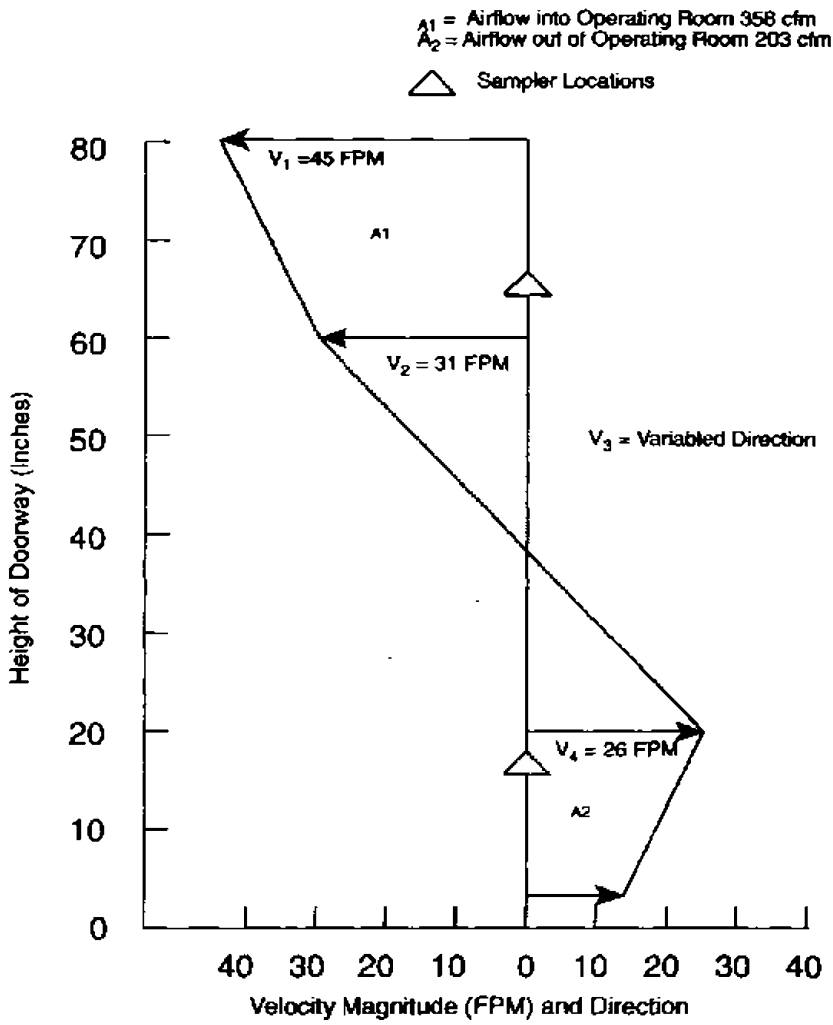
This year also published Tables on Airborne Bacterial Counts and filter efficiencies for removing biological particulates.

The 1964 chapter was renumbered to 29 and renamed to simply "Hospitals" but otherwise the text remained virtually unchanged. At this time the editing of the chapter was indicated to be assigned to Technical Committee TC 6.2 "Large Building Air Conditioning." In 1966 and 1967 the first topic title (The Infection Problem) was dropped but otherwise there were no textual changes.

The 1968 chapter, now numbered 14, dropped the table on filter efficiencies and replaced it with text describing NBS dust spot testing, protection of filters during construction, and some applications of various filters. The Air Movement section was expanded this year introducing the concept of ceiling supplies and floor returns in clean areas. In addition, a new figure and accompanying text introduced an important issue which will appear in our recommendations. The text reads, "The opening of a door or closure between two such areas instantaneously reduces any existing pressure between them to such a degree as to nullify the effectiveness of the pressure" (ASHRAE, 1968). Figure 1 shows the air velocity vectors in an elevation of an open door.

The *1968 Guide and Data Book* also introduced the now familiar Table 3 with the following text "Table 3 gives the recommended minimum ventilation rates for the various areas of the hospital." The table has the format used to this day showing pressure relationships, minimum outside air changes, minimum total air changes, air exhausted and air recirculated with the room allowances for various spaces. The first such *Guide Book* table has some changes from air changed rates recommended in the previous year's guide book. A comparison of the air change rate values over the years is in the Tables section of this paper.

Between 1968 and 1971 the chapter underwent significant change. By 1971 it was numbered Chapter 15 and entitled "Hospitals and Related Health Facilities." The first major title in the chapter



Velocity Distribution through Operating Room Doorway (Room Not in Use)

Figure 1

became Air Conditioning in the Prevention and Treatment of Disease. This was a return to the title of the entire 1959 chapter. In this section was a well-documented and scholarly description of the effects of humidity and temperature on respiration and body heat loss. Figures were added to show, among other things, heat and water exchange during respiration. The topic of Application

of Air Conditioning to Health Facilities reintroduced The Infection Problem which had been previously eliminated. The primary contagion discussed under this topic was *Staphylococcus aureus* but many of the basic principles for infection control described then are still relevant today for other infectious agents. The remaining two main topics were Air Conditioning Systems and Design Criteria, the latter then becoming the permanent home to Table 3 on air change rates.

The 1974 edition of the chapter appeared in the *Applications Handbook* and began a pattern of occurring every 4 or 5 years. It became Chapter 7 and was entitled simply "Health Facilities" a title and number which has with one exception in 1987 remained the same to this day. This year also marked the reassignment of the chapter editing to TC 9.8 "Large Building Air Conditioning Applications," a shift foretold by the previous editions topic on application of air conditioning to health facilities.

The *1978 Applications* Chapter 7 was the product of some severe editing which reduced the length from 14 pages to 10 and the references from 42 to 10. For the first time and forever since, one of the references was the US Dept.of HEW 1974 "Minimum Requirements of Construction & Equipment for Hospital and Medical Facilities," now more commonly referred to as the "AIA Guidelines." In this year the figures on respiration were removed along with most of the text surrounding them. Table 1 which had been titled "Airborne Bacterial Counts Found in Hospital Environments" was now replaced with a new Table 1 on the recommended minimum filter efficiencies and their applications which, with some modification, had appeared in previous editions of the chapter as text, and then was dropped. Beginning with this year, Table 3 divided the operating room air change rates into recirculating and all-outside air values. There were also several significant reductions in the amount of outside air recommended in spaces such as recovery, delivery, patient rooms, intensive care, isolation, anterooms, X-ray, laboratories, autopsy, and especially food preparation which had been previously listed at twenty air changes of outside air. These changes were undoubtedly due to

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

operating room applications. A new section in infection sources states that *Aspergillus* species can cause an untreatable and often fatal disease. The topic title "Design Criteria for Principal Areas of an Acute General Hospital" was dropped but most of the text remains the same as 1987. This edition, like the previous, makes reference in the text to DHHS pressure relationships and air change rates in health care spaces by saying that it is not intended for the two guidelines to agree completely. The guidelines also state that, in those few cases where ASHRAE Standard 62-1989 requires higher outside air quantities, Standard 62 should be followed. Reference is made to NFPA 90A, 92A, and 101. Table 3 added a recommendation for Delivery rooms using 100 per cent outside air and a new line for Labor, Delivery, Recovery and Postpartum (LDRP) rooms. The typical patient room total ventilation was changed from 2 ACH to 4 ACH. Another Standard referred to for the first time is the Safety Code for Mechanical Refrigeration (52-1989). Table 5, the pressure relationships and air change rates for nursing homes, is dropped in this edition.

The current chapter contains several ideas that date back to as far as the 1962 chapter and have survived the repeated edits of various TCs over those years. Table 2 and Figure 1 date from 1962 as well as Specific Design Criteria regarding Nurseries, Radiology, Laboratories, Pathology, Autopsy, and Pharmacy.

In some ways paralleling the work of ASHRAE, the DHHS has developed, first *General Standards in 1947*, then *Minimum Requirements* in 1973, and finally *Guidelines for Construction* in 1984. These documents, like the original Federal Register publication, containe information which pertains to all aspects of health care design including architecture and equipment as well as engineering. The latest edition of the *Guidelines* (1992) has just been released and for the remainder of this paper it will be referred to as AIA.

Although these two guidelines have been available since 1947, designers historically have had only to adhere to what a local building code and State Department of Health rule required by law.

Ventilation designs in hospitals therefore, followed original construction specifications and ongoing maintenance according to the period of construction and/or renovation. The quality of the design often was contingent on the funding source for construction. Early construction used designs which included neutral air pressure relationships for isolation rooms. Subsequent design guidelines were explicit with respect to pressure controls and filtration requirements in isolation rooms construction from about 1962 on. The ventilation design before that time depended upon the hospital planning awareness towards the control of infectious disease. Such efforts to cohort and isolate patients have been a clinical practice for years extending back to the days of Florence Nightingale. Historical efforts to contain patients with infectious disease have occurred in the time of increasing sophistication in ventilation systems. The plumbing codes providing for bathroom exhaust were probably the initiation of ventilation control in patient rooms. The engineering premise to supply air for makeup to the exhaust system then initiated the need to bring in outside air. Because of the variation in designs over the history of health care facility construction the importance of understanding the current concepts for airborne spread of infectious disease and the role of ventilation in the control of that spread is important.

EXISTING DESIGNS—NEW BUILDINGS

Ventilation Systems

General Ventilation

In many ways, the modern hospital has many of the same design needs of any typical air conditioned space. Air is introduced for the dual purpose of absorbing heat within the space and resupplying oxygen. Air is removed from the space with the absorbed heat and carbon dioxide generated by occupants. There are a number of techniques employed to accomplish these tasks, most of which are applicable to the hospital. For the purposes of this section, we will direct our attention to the design applications which pertain to the movement of air within spaces. Later on we will discuss

airflow rates, airflow distribution, intake and exhaust issues, outside air rates and general maintenance concerns.

Patient Rooms

Most modern hospital construction utilizes central air handling systems with ducted supply and return air to each room. These rooms generally are provided with individual temperature controls which operate some type of heating or cooling modulation for that room. The distribution system may be single duct, constant volume with reheat; single duct, variable volume, with or without reheat; dual duct with individual room mixing boxes; or single duct primary air to individual fan-powered boxes. Air can be distributed to the room through diffusers set in the ceiling or a sidewall. Air removed from the room may be taken up by return grills set in the ceiling or sidewall. Often special purpose rooms will use low sidewall return systems. If the quantity of air supplied to the room is low, all of the air may be removed through the patient toilet exhaust. This has the benefit of a low first cost but does not allow for upgrading the room to a more ventilation intensive specialized purpose in the future. When air is purposefully delivered at a low volume, such as the minimum AIA guideline of two ACH, the excess heat present in the room can be removed through a water based system such as a valance or radiant panel. Such systems can become difficult to maintain and are prone to condense moisture if the chilled water temperature is below the dew point of the room air. In this event the panel or valance fin tube is more of a liability than a benefit. Systems which have fallen out of favor include through-the-wall unit ventilators; all-air induction ventilators; two-pipe and four-pipe fan coils; and window air conditioners. Some states discourage or ban altogether the use of variable air volume systems.

Isolation Rooms

As a special case of the general patient room, the isolation room receives particular attention during the design of the modern health care facility. The current situation in hospital isolation rooms has been away from cohorting persons with similar diseases. Isolation rooms have been often moved to a specific patient care

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.

Radiology

Modern radiology departments are areas of frequent change in the type and quantity of equipment used and the resulting impact on the building systems they require. All too often, it is only after new equipment is installed and running that the inadequacy of the ventilation to maintain an appropriate environment is discovered. For this reason, the ventilation in these department spaces receive more than the normal level of interest and attention. The attention, however, is generally due to comfort rather than infection control issues. That may be changing now that patients who are being transported from their rooms to the radiology department for diagnosis and treatment (D/T) are increasingly themselves at risk or place others at risk of infection. The diagnostic and treatment procedures within medical imaging and theraputic radiology are becoming of longer duration and more invasive. Both guidelines are recognizing these changes by recommending air change rates separately for D/T and surgery. When the X-ray power equipment is located with the treatment room there generally is adequate ventilation to control heat gain. When the power equipment is in separate rooms the designer will usually follow the minimum recommended volumes in the guidelines. Air distribution in the treatment room will be similar to the patient room.

Waiting Rooms, Admitting, and the Emergency Department

In the 1962 ASHRAE Guide and Data Book a simple statement is found regarding these types of spaces: "This area requires no unusual air treatment and should be conditioned for comfort of the occupants." This language remains in ASHRAE up to the latest edition. AIA does not address these spaces. These spaces should not be overlooked. The emergency room waiting and admitting area in which ASHRAE recommends 10 ACH and negative pressure should be considered for local ventilation.

Local Ventilation

Local ventilation, usually exhaust systems, have historically been used for a variety of purposes including infection control. Scavenger exhaust of respirated anesthetic gases have been common as have laboratory hoods for chemical fumes, biological research and testing, and radioisotope labeling.

Special Procedure Rooms

Special exhaust systems used in gastroenterology and endoscopy are becoming more common. There is a growing use of local patient hoods which recirculate air through HEPA filters during medicated aerosol treatment of HIV patients. These hoods are generally not of any standard construction and may have been designed in-house and built in the hospital shops. Because the very nature of their use (sputum induction, bronchoscopies, or aerosolized pentamidine administration) generates large quantities of sputum droplet nuclei there is an inherent risk of spreading infection. At present, the design guidelines do not address this consideration of health care ventilation. Research is needed in both the area of effective design of these patient hoods and of the general ventilation in the room where they are used.

Operating Rooms

The entire operating room in some cases is considered a local ventilation system. Depending upon the type of surgery done in the room the ventilation can vary from vaned ceiling diffusers or sidewall diffusers which ensure complete mixing of air, to highly specialized systems with over one hundred ACH through HEPA filters in a near laminar flow distribution. There is no consensus on the appropriate system for these rooms and so designs as well as opinions vary widely. What is agreed upon universally is the desire to prevent infection of the open wound. To that end most systems employ a combination of displacement and local ventilation. The locale however, is considered only the wound site and not the room at large. Nor do most designs consider how an infectious disease (airborne) might affect the operating team. Here is an example of a potential application of the patient hood for this purpose. The patient is immobile and may already have some sort of respiratory control. A local exhaust system which removes the respirations directly to the outside even for patients under local anesthesia could be effective.

Air Cleaning

General ventilation is completely dependent upon clean air from the central ventilation system. While building codes and state department of health rules still recognize open windows as an

equivalent ventilation system in the health care facility modern design has all but eliminated the practice. Both AIA and ASHRAE are very specific in the recommendations for filter efficiencies for various applications. Recently, the guidelines have adopted the use of 99.97% (HEPA) filters in certain applications such as protective isolation and orthopedic surgery. There is some evidence that a design which includes filter efficiencies of 90-95% throughout the entire hospital has a beneficial effect on the incidence of *Aspergillus* nosocomial infection (Streifel, 1993).

The Centers for Disease Control and Prevention (CDC) has recommended that air potentially contaminated with infectious disease be HEPA filtered prior to being recirculated. In practice, this is seldom designed even though the recommendation dates from 1990. There are two reasons for this: 1) Air that is not exhausted directly outside is not identified as potentially containing infectious disease by the health care institution. Design professionals also do not make such a designation for this air. 2) Filters are not located in recirculated air streams. The accepted design for filter location place them in the supply air systems only. This means the mixture of outside air and recirculated air (called mixed air), is conditioned, and then is filtered before being distributed throughout the building. Figure 2 shows this concept of filtering supply air as opposed to recirculated air in central air handling systems.

Research is needed in determining the optimal efficiency of filtration to prevent the spread of respective airborne infectious disease. Since the airborne particle size of one infectious disease may be different from that of another, the filtration would need to be established for the worst case. However, if the worst case particle size was a virus, the efficacy of filtration would be in doubt. Also, the probability of infection by the airborne virus varies with the virus concentration in the air and the generation rate of virus in the space. In this case, outside air would be preferable to filtration as a dilution air source. Filtration may best be used for the fungi and bacteria particles (>1.0 microns). Filtration efficiencies have been evaluated and the 90-95% effi-

cient filters have been shown to remove > 99.9% of the > 1.0 micron viable fungal particles (Rhame, 1990).

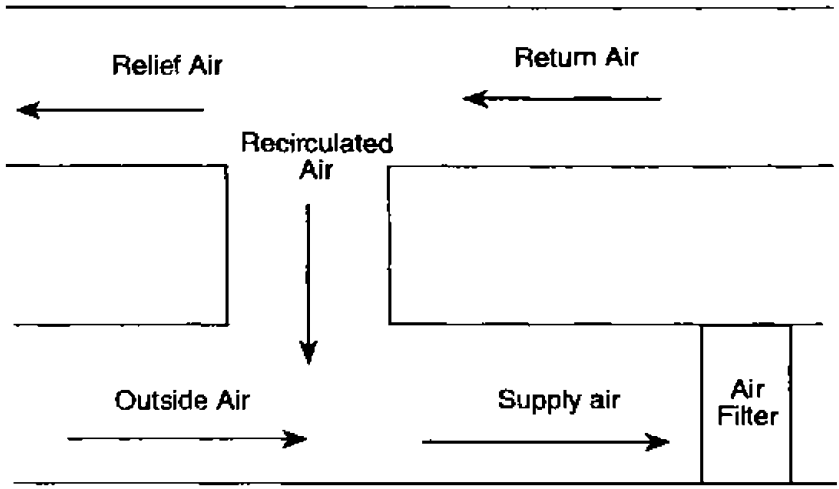


Figure 2.

Retrofit

When one of the model code making bodies produce a new or revised building code, it is usually in response to input from the various authorities having jurisdiction around the country. An incident or a series of incidents prompt a review of the model code and new language is drafted, debated, and ultimately voted on in open meetings. Once adopted, individual states who subscribe to the model code will review the language and either adopt it by reference or perhaps write an amended version. Then the new proposed state code undergoes the rulemaking process which includes public hearings. All of this takes a lot of time to implement. It is not unusual to have several years pass between the first draft of the model code and the completion of the state rulemaking process. During the entire process, buildings continue to be designed and constructed under the existing code. When the new code becomes law it has an effective date which pertains only to new designs which are reviewed and not to any

previous. All existing construction is also "grandfathered." This concept is important to the issue of retrofitting existing health care facilities to new standards. If the authority having jurisdiction has a rule which sets the conditions under which retrofit falls under the new codes and not the old, health care institutions planning a retrofit may consider this when deciding how much work to accomplish at once. This, along with each particular institution's financial status, has much to do with the condition of the physical plant in the hospital industry. Therefore, the types of retrofit which have the most impact on improving infection control and have the best chance of being implemented are those which:

- Are driven by the institution's clinical staff and supported by the administration.
- Are located in states with either strong state rules or a very competitive marketplace.
- Are driven by an identified source of an epidemic of nosocomial infections. In our case those implicating the ventilation system.
- Are easy enough and inexpensive enough to be accomplished by any institution in a short time.
- Are logical and easily understood by the average ventilation design engineer.
- Are backed by creditable research for their efficacy.
- Are endorsed by CDC and NIOSH.

It is a wonder how any retrofitting happens at all.

In any discussion of what is happening in the industry today we must first describe the condition of the existing space and the new use to which the space is being modified. Since there are uncountable variables in describing the existing spaces we will choose a few examples of hypothetical patient rooms, isolation rooms, including protective isolation, and special procedure rooms. In each case we will choose the type of ventilation design with the greatest potential for a successful retrofit. The recommendations will describe those ventilation systems which for one reason or another are not good candidates for retrofit.

Patient Rooms

A patient care unit designed and built in the 50s or early 60s is served by medium pressure all-air induction units each with about 50 cfm of primary air which is 100% outside air. The induction units are either four pipe or two pipe with a summer/winter change over. There is a drip pan under the coil and no air filter.

These units are typical of the period and were popular designs. The problem is the drip pan and the coil collect dirt and are often wet from cooling. They are maintenance headaches and potential sites for microbial growth. Buildings using this design frequently have low floor to floor heights and relatively high room ceiling heights. Windows are openable and are quite tall. The toilet room, if there is one, has an exhaust equal to the quantity of the primary air to the induction unit.

Just about any retrofit of this system is expensive. The space available for ductwork is generally the ruling factor. If space is available, a totally new ducted low pressure air supply system is often suggested. However, since the quantity of outside air delivered is adequate to satisfy the newly released AIA guideline new ductwork may not be indicated. By focusing on two primary problems 1) the age and location of the induction coils, and 2) the control of the cooling, a less expensive solution often is suggested: removing all induction units, ducting the medium pressure primary air to new ceiling-mounted fan-powered boxes hidden above a dropped ceiling, and replacing the temperature controls to limit the temperature of the cooling to stay above the highest expected dew point temperature of the room. The fan-powered box is installed with 90-95% efficiency filters (generally a custom modification). Often in buildings of this age new windows are suggested to help reduce the cooling and heating load and the air infiltration.

Infectious Isolation Rooms

A patient care unit built in the late 60s or early 70s has a central air handling unit supplying four ACH to the patient rooms. There is no isolation room on the unit and one room is to be converted. It is to be designated as an acid fast bacillus (AFB) isolation room.

There is no anteroom. This retrofit will form two broad categories, architectural modifications and, ventilation modifications.

Architecture

Architecturally, the room receives a new sheet rock or plaster ceiling; either surface mounted light fixtures or recessed without air vents and sealed to the ceiling; seamless vinyl flooring; vinyl wallpaper walls; a headwall for medical gases and power-sealed to the ceiling; no plumbing fixtures in the room to provide an opening through the walls; a slow opening and fast closing door opener on the inward swinging door; a relatively loose fitting door, i.e., one which will allow a good volume of air to pass under it from the corridor into the room; and the same type of door on the toilet room which opens into the room. If the patient room is without a toilet room one should be added. The toilet room should have similar floor, ceiling, and wall finishes. The plumbing pipe openings should be sealed to the wall.

Ventilation

The return air ductwork to the room is cut and capped. The return grill to the room is either connected to a nearby isolation exhaust duct system or the room toilet exhaust. The grill is relocated to one of two places, either low along the wall between the patient bed and the outside wall, or in the ceiling somewhere between the bed and the outside wall. The supply air is rebalanced to provide at least 6 ACH, and the total exhaust from the toilet and patient room combined is increased to between 50 and 75 CFM, more than the supply needed for cooling or 6 ACH, whichever is higher. The room may or may not receive a air pressure monitor which will continuously monitor the relative pressure between the room and the corridor. This monitor will contain an alarm indicating an adverse condition. It may also have some control capability which would attempt to correct the adverse pressure by reducing the flow of supply air to the room. Obviously, if the control becomes too severe, the room comfort will suffer. Some alarm condition can be used to indicate the limit of the control functions ability to correct pressure problems.

into service without much in the way of ventilation modification. Yet these procedures generate some of the highest levels of airborne infectious particles (Catanzaro, 1982). Little is being done to standardize these types of rooms partly due to the rapid appearance of their use and the general slowness of the guideline modifications.

Building Air Intake and Exhaust

Few topics of building engineering design solicit more grisly tales of horror than that of air intakes and exhausts. Carl W. Walter cited several examples in a 1980 publication (Walter,1980).

A state university hospital was designed with a below grade air intake plenum whose walls extended 8 feet above grade. This plenum was common to all air handlers in the hospital. After numerous infection outbreaks an investigation revealed "that the screen behind the ground level intake louvers was choked with trash, leaves and wood chips from manure that had been spread over the unplanted courtyard." Similar debris had accumulated on the floor of the intake plenum. The air handling units had recirculation water spray air scrubbers. The water as well as the cooling coils were respectively murky and slimy.

A second example, this time a Veterans Administration Hospital, experienced mixed clostridial and gram negative wound infections. "Inspection revealed pigeons roosting in the intake plenum of the air conditioning system. Eight inches of guano and the decomposed carcasses of a half dozen birds littered the floor. The filters, laden with molding dust, had dropped out of their frames and the refrigerating coils were a confluent mass of slime and mold."

A third example is of a university hospital's cardiac catheterization laboratory. Air samples showed heavy contamination of *aspergillus* and *S. epidermidis*. "It was air conditioned by a domestic type window unit that projected over a trash compactor. Its filter was moldy. Its refrigeration coils and fan were slimy." Obviously, lack of proper maintenance played a major part in each of

these examples. In most cases however, a design sensitive to the needs of clean air will prevent or minimize these sort of problems. Examples of good practice include the following designs:

- Exhaust fans are located at the discharge end of the distribution system with pressurized ducts run only in mechanical rooms.
- Outside air intakes are located at least 25-30 feet from exhaust outlets, combustion stacks, medical vacuum exhaust, plumbing vents, or any other noxious fumes, (such as trash dumpsters).
- Outside air louvers are placed as high as possible but at least six feet above grade or at least 3 feet above a roof. The prevailing wind and site conditions around the building are considered and may increase these minimum distances.
- Bird screens are no smaller than one-quarter inch mesh.
- Intake plenums are adequately drained.

In certain settings, outside air may not be the best source for clean air used in dilution ventilation. Although criteria exists to determine the acceptability of outside air for general indoor air quality purposes (ASHRAE, 1989), specific health care facility requirements have not been published. There appears to be a gap in the literature regarding any special needs the health care community may have to pretreat outside air before it is admitted. Traditionally, air which is recirculated is not conditioned independently from outside air. Independent conditioning processes such as filtering may be useful in locations where the outside air is particularly polluted.

Airflow Rates

Among the most controversial aspects of the engineering control of airborne infection are airflow rates. Existing guidelines are specific in prescribing the relative quantities of total air movement in various

health care spaces and of that portion of the total air which must come from outside. Much confusion develops over these prescriptive requirements because neither AIA nor ASHRAE describe their basis or origin. As we have seen in the history, airflow rate prescriptions go back at least to 1947 when ventilation systems in all buildings including hospitals were strictly intended for human comfort. Sometimes even that design criteria was poorly met. Today, health care space designs are constrained by forces which include liability and costs of construction as well as energy. The new or inexperienced health care ventilation engineer is met with a bewildering array of sometimes conflicting requirements, guidelines, hearsay, and prejudice which try to influence the design. Frequently, long established engineering firms with traditions of service to this industry will follow one or a very small set of design criteria, forsaking all others in order to bring some sense to the chaos. This also serves to limit the time spent on research of alternate designs.

Since the mandatory requirements for construction needed to obtain construction grants under the Hill-Burton act became merely guidelines it has been up to either the State Department of Health or the health care organization itself to establish minimum criteria for design including airflow rates. On occasion the health care organization will employ the services of the epidemiologist or orthopedic surgeon to assist the ventilation engineer in establishing criteria for air change rates. Facilities with active research in such areas as transplant surgery, orthopedic surgery, bone marrow transplants, tuberculosis, or HIV Clinics may have requirements for specific rooms which may not be covered in the design guidelines.

Medical centers of excellence are frequent across the country and many very good designs are in place which never are shared in the literature. By the same token, some gruesome designs are in place which barely serve their present function, sometimes because of poor design, but more frequently because the space was never designed for the present function it serves. It is sometimes amazing to see the number of otherwise ordinary patient rooms, which may date back to the early Hill-Burton construction designs that are pressed into service as isolation rooms, often with little or

no modification to the ventilation system. The section on retrofit addresses some of the ways in which these conversions are accomplished with mixed success.

Table 6 lists the air change rates presently published in the AIA and ASHRAE documents. Various states have adopted, or modified these, usually upwards, and other states have published entirely separate requirements. Some states have no requirements beyond the original Hill-Burton language of the late 40s or early 50s.

It has largely been the influence of third party payers such as Medicare and Medicade as well as the private insurance industry which has driven health care organizations to adopt ever more stringent standards for minimizing the spread of airborne infectious disease by ventilation systems. On the other hand, it has been the desire of limiting the rising cost of health care construction and building operation which has prevented universal acceptance of guidelines where they are not backed with the force of law.

The health care facility design community is at best not unanimous and is often divided on the issue of increasing minimum airflow rates, especially in isolation rooms and operating rooms, for the purpose of minimizing the spread of infection. At even greater discord is the issue of differential pressure between spaces for the same purpose.

It can be safely said that although there has been much published about the spread of infectious disease and the possible implication of the ventilation system in epidemics, little research in how ventilation systems effectively control airborne diseases within spaces is apparent. Research is needed in this area. Such research, although obviously in need of careful input from the medical community, is best conducted from the ventilation engineering viewpoint.

Air change rates, such as those listed in Table 6 are the result of many years of practical and often empirical study. Some space airflow rates listed have had more scientific research than others. Some have been handed down from revision to revision and swapped between one guideline to another, having lost in the

process the original research which was their basis. To challenge them now could be likened to closing the gate on an empty corral. To stretch the metaphor, we, like the farmer, need livestock in the barnyard in order to be creditable.

Airflow Distribution

The primary role played by mechanical ventilation is that of maintaining a comfortable environment in the space ventilated. This is as true in health care settings as much as in other general buildings. The role of moving air in a space being used for infection control is not often used and very little understood. The most notable exception is the so-called laminar flow system for operating rooms, so-called because true laminar flow spaces, the sort used in computer chip manufacturing, require elaborate floor or wall plenums to receive the parallel airflows without restriction. Today the operating suites which contain banks of HEPA filters in the ceiling or a wall generally have more conventional return/exhaust grills. Still the concept of using air as a mechanical force to direct particles to behave in a predictable fashion has been used in several health care settings including fume hoods, scavenger exhaust, and of course operating rooms. The entire concept of local ventilation depends upon the velocity of air directing fumes or particles to be captured and either trapped in a filter or simply exhausted outside. Dilution ventilation has as its basic premise a dependence on complete mixing of air and contaminants. The air distribution in a room becomes at least as important as the quality and quantity of that air.

Fortunately, diffusers which distribute air with the intent to provide a comfortable temperature also do a fairly good job of mixing contaminants with the clean incoming air. There are still pockets of stagnant air present in just about any diffuser layout which could create areas of static infectious particles. These stagnant areas need to be minimized in the design which is considered infection control. ASHRAE has developed a standard which evaluates the performance of room air diffusion. The standard is a method of testing temperatures and velocities at various locations in a room and from the measurements calculat-

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

handling systems provide only one ratio of outside air. This is also a valid argument against variable air volume systems which tend to favor recirculated air when total volumes are reduced.

Since the ACH values listed are only minimums it becomes necessary to increase the total volume of air to each room until the correct minimum quantity of outside air present in the supply air is reached. Therefore, AHUs with higher outside air ratios may supply lower total air volumes to satisfy the minimum outside air. For example, the 1991 ASHRAE recommendation for patient rooms is 4 ACH with 2 ACH of outside air. If the typical 1000 cubic foot single patient room received 4 ACH of fifty percent outside air both minimums would be met with about 66 CFM of total air. However, if the air delivered were 30 percent outside air then in order to meet the 2 ACH the total air delivered needs to be about 110 CFM (33/0.3). Both minimums are still met but more total air is delivered if the ratio of outside air is less. In this way each space of the facility can meet the intent of the guideline with air delivered by a central air handling unit of a fixed outside air percentage. Establishing what the fixed outside percentage will be is and should remain the decision of the ventilation design engineer. In practice, the modern health care facility usually requires more than the minimum total air in order to meet the comfort requirements.

Maintenance

The previous discussion regarding outside air intakes and exhaust systems establishes the critical need to properly maintain the health care ventilation system. Although these examples are particularly dramatic the more common situation is one of generally good care. The typical hospital engineering department is well aware of the need to replace filters, clean air intakes and exhaust plenums, and monitor general operation of the ventilation system. It is true that the larger institutions have somewhat more flexibility to program preventive maintenance due to larger staff sizes but this is changing due to cutting of department budgets. Much good has been done by the Joint Commission for the Accreditation of

Healthcare Organizations to lift the awareness of both maintenance and administrative staffs to the importance of maintenance planning and record keeping. Often the infection control department will work with the maintenance department to combat some problem which may have manifested in a nosocomial infection outbreak associated with the environment. On these occasions awareness of maintenance of the ventilation system becomes apparent and if necessary greater attention to operational efficiency is required.

Routine regular cleanings of patient room supply and exhaust grills are the best method of preventing air balance problems caused by clogging. Rooms with low sidewall exhaust grills are particularly susceptible to dust and lint from the floor. Operating rooms as a rule collect scrub lint in their returns. Special care is often given to humidifiers within duct systems. When any direct water injection, either by steam or cold water, is made into the air stream a potential for biological growth exists. Certain areas of the country still use evaporative cooling even in health care settings. These devices are particularly prone to harboring microbes which could grow to a point where they become entrained into the air. Maintenance procedures for these types of water/air mixtures generally are repeated more frequently to minimize such growth.

The availability and acceptance of computerized scheduled maintenance has allowed the modern hospital engineering staff to plan more effectively the necessary resources to accomplish the difficult task of maintaining today's highly technological mechanical and electrical systems. Some institutions are moving beyond preventive maintenance into predictive maintenance which will with some accuracy predict failures to critical building systems before they happen. This allows scheduled shutdowns to make repairs or replacements without the stress of the emergency outage.

RECOMMENDATIONS

Short Term recommendations

We must do whatever is economically possible in the short term to bring all health care facilities up to a minimum level of protection against the spread of some airborne infectious diseases, namely tuberculosis. That minimum level should include:

- At least one isolation room with an anteroom in each facility which meets the minimum requirements for AFB isolation described below.
- A program of minimum maintenance on the mixed air dampers, the filters and coils, and the air balance in the isolation room(s).
- A plan which outlines the timetable to bring the entire facility up to the present guideline recommendations for air filtration, outside air volumes, and total air volumes.

Minimum requirements for AFB isolation

The minimum requirements for a completely sealed single patient room are the following:

- Plaster or sheet rock ceilings, either surface mounted light fixtures or fixtures without vents caulked to the ceiling. Horizontal surfaces should be cleanable with no penetrations other than sealed electrical outlets.
- Headwalls for medical gases sealed to the ceiling.
- Air supply diffusers which have an Air Diffusion Performance Index (ADPI) of 80 percent or more.
- Low sidewall returns in the patient room between the outside wall and the patient bed.
- At least 12 air changes per hour of 90 percent filtered air.[1]
- All air exhausted out of the room through a fan system dedicated for isolation exhaust.

[1] Variables are a 1 in 20 chance of infection for a stay of 30 minutes; 60 qph, 210 CFM, a 1000 cubic foot room.

- The exhaust fan mounted on the roof or in a penthouse with a minimum of positive pressure duct.
- An ante room containing a sink and storage.
- At least 20 ACH in the ante room of exhaust going to the same isolation exhaust fan system and no supply for makeup air with both doors opening into the ante room arranged so that the swings intersect.
- Both doors on automatic door closers with slow open and quick close mechanism and no weatherstripping on the doors to allow air to flow through them.
- An electronic or pneumatic monitor to constantly measure the differential pressure of the patient room with respect to the corridor and alarm when the relationship changes.

This suite of rooms (patient, toilet, and ante room) should be left in infectious isolation condition at all times, even when used for non-infectious patients. Emergency room facilities should provide rooms with the same criteria for isolating a suspect emergency patient with an infectious disease.

Maintenance for air handling systems

The CDC and NIOSH should commission the American Society of Hospital Engineers (ASHE) and ASHRAE to develop and publish minimum required maintenance procedures for filter changing, as well as coil, diffuser and duct cleaning. These requirements should include maintenance of mixed air damper operation and their controls. At least semi-annually, each air handling unit (AHU) should be stopped and its interior inspected for filter integrity. The mixed air dampers should be operated through their full range of motion, the coils should be measured for pressure drop due to dirt. When the fan is operating, the mixed air, outside air and return air temperature should be measured as a means to determine the percentage of outside air being admitted. The volume of air entering and leaving the isolation room(s) should be measured. All of the above should be recorded. Routinely a smoke stick should be used to verify airflow movement in the designated ventilation controlled isolation rooms.

Long Term Recommendations

Outside Air

Since outdoor air is not always the best source for clean air used in dilution ventilation, pretreatment to remove particulates and gases should be installed. In new design, the outside air intakes should be above the roof. If mechanical equipment rooms are not in penthouses then outside air shafts communicating with the roof should be provided. Exhausts for removal of infectious air should be designed for minimum effective stack heights of 35 feet. The fan should be mounted outside on the roof with a vertical discharge of 3000 feet per minute or more.

Airflow Rates

The volume of outside air to a space which contains a source or a potential source of airborne infectious disease should be designed for controlling the concentration of infectious doses present in the air. The design then becomes based on the concept of assumed risk. It can be shown that the probability of an infection in a ventilated room is dependent on the variables found in the Reed-Frost equation (Riley, 1989).

$$C = S(1-e^{-Ipqt/Q})$$

where:

- C = number of susceptibles S who become infected
- S = number of susceptibles
- I = number of sources (already infected)
- p = pulmonary ventilation in volume per unit time
- t = exposure time (minutes)
- Q = removal rate by fresh air (CFM)
- q = number of doses of airborne infection added to the air per unit time by a case in the infectious state

If the quanta (q) can be determined for each disease in each type of room or each procedure then the design parameters of the ventilation system will depend only on the level of risk allowed and the time a susceptible person spends in the room.

Assume for the moment that a 1 in 10 chance of infection is acceptable. An isolation room with an active TB patient could be ventilated such that a person entering without a mask could stay in the room for a length of time dependent upon the ventilation rate in the room. The longer the stay the higher the risk of infection. If long stays are needed the ventilation could possibly be increased for the duration of the stay then be returned to some base line level.

In a modern isolation room of about 120 square feet and 6 ACH of 95 percent filtered air Q would equal about 100 cfm, however, since the filter efficiency is 95% only 95 cfm can be considered clean. This assumes that the filter can stop 95% of the particles needed for infection. If the particles are virus size the filtration dilution volume would default to the volume of outside air. A quanta calculation of a tuberculosis patient in a hospital setting set q at 60 qph (Riley, 1962).

Solving for t:

$$t = -Q/Ipq * \ln[1-(C/S)]$$

where: $I = 1$
$p = 0.352$ cfm
$C = 1$
$S = 10$

With these variables, the time (t) becomes a little less than 30 minutes.

Using this logic a table can be developed listing the airflow rate along one axis, the time spent in the room along the other and the probabilities of infection for each cfm at each length of stay (Tables 1 through 5). Such a table would be specific for each infectious disease and each type of ventilation system. The ventilation system is important because of the assumed air mixing in the formula.

The obvious need for research is to establish standard quanta (q) for each disease. The quanta also will vary by the ability of the susceptible to fight off the infection before symptoms occur. Therefore, the quanta will depend upon who is being threatened

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.

TABLES

PROBABILITIES OF INFECTION

Table 1

QUANTA = 1.25

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.001	0.003	0.004	0.006	0.007	0.009	50
0.001	0.002	0.003	0.004	0.005	0.006	75
0.001	0.001	0.002	0.003	0.004	0.004	100
0.001	0.001	0.002	0.002	0.003	0.004	125
0.000	0.001	0.001	0.002	0.002	0.003	150
0.000	0.001	0.001	0.002	0.002	0.003	175
0.000	0.001	0.001	0.001	0.002	0.002	200
0.000	0.001	0.001	0.001	0.002	0.002	225
0.000	0.001	0.001	0.001	0.001	0.002	250
0.000	0.001	0.001	0.001	0.001	0.002	275
0.000	0.000	0.001	0.001	0.001	0.001	300

Table 2

QUANTA = 13

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.015	0.030	0.045	0.059	0.074	0.088	50
0.010	0.020	0.030	0.040	0.050	0.059	75
0.008	0.015	0.023	0.030	0.038	0.045	100
0.006	0.012	0.018	0.024	0.030	0.036	125
0.005	0.010	0.015	0.020	0.025	0.030	150
0.004	0.009	0.013	0.017	0.022	0.026	175
0.004	0.008	0.011	0.015	0.019	0.023	200
0.003	0.007	0.010	0.014	0.017	0.020	225
0.003	0.006	0.009	0.012	0.015	0.018	250
0.003	0.006	0.008	0.011	0.014	0.017	275
0.003	0.005	0.008	0.010	0.013	0.015	300

Table 3

QUANTA = 60

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.068	0.132	0.191	0.246	0.297	0.345	50
0.046	0.090	0.132	0.172	0.210	0.246	75
0.035	0.068	0.100	0.132	0.162	0.191	100
0.028	0.055	0.081	0.107	0.132	0.156	125
0.023	0.046	0.068	0.090	0.111	0.132	150
0.020	0.040	0.059	0.078	0.096	0.114	175
0.017	0.035	0.052	0.068	0.084	0.100	200
0.016	0.031	0.046	0.061	0.075	0.090	225
0.014	0.028	0.041	0.055	0.068	0.081	250
0.013	0.025	0.038	0.050	0.062	0.074	275
0.012	0.023	0.035	0.046	0.057	0.068	300

Table 4

QUANTA = 93

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.104	0.197	0.280	0.354	0.421	0.481	50
0.070	0.136	0.197	0.253	0.306	0.354	75
0.053	0.104	0.151	0.197	0.239	0.280	100
0.043	0.084	0.123	0.161	0.197	0.231	125
0.036	0.070	0.104	0.136	0.167	0.197	150
0.031	0.061	0.090	0.118	0.145	0.171	175
0.027	0.053	0.079	0.104	0.128	0.151	200
0.024	0.047	0.070	0.093	0.114	0.136	225
0.022	0.043	0.064	0.084	0.104	0.123	250
0.020	0.039	0.058	0.077	0.095	0.113	275
0.018	0.036	0.053	0.070	0.087	0.104	300

Table 5

QUANTA = 249

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.254	0.443	0.585	0.690	0.769	0.828	50
0.177	0.323	0.443	0.542	0.623	0.690	75
0.136	0.254	0.356	0.443	0.519	0.585	100
0.111	0.209	0.296	0.374	0.443	0.505	125
0.093	0.177	0.254	0.323	0.386	0.443	150
0.080	0.154	0.222	0.285	0.342	0.395	175
0.071	0.136	0.197	0.254	0.307	0.356	200
0.063	0.122	0.177	0.229	0.278	0.323	225
0.057	0.111	0.161	0.209	0.254	0.296	250
0.052	0.101	0.148	0.192	0.234	0.274	275
0.048	0.093	0.136	0.177	0.217	0.254	300

Table 6

ASHRAE AIR CHANGE RATES OVER THE YEARS

(TOTAL AIR/OUTSIDE AIR)

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991
OR											
100% OA	8-12	15	15	15				15	15	15	15
RECIRC					25/5	25/5	25/5	25/5	25/5	25/5	25/5
DELIVERY											
100% OA		15	15	15							15
RECIRC					25/5	25/5	25/5	12/5	12/5	12/5	12/5
RECOVERY		4	4	4	15/6	15/6	15/6	6/2	6/2	6/2	6/2
NURSERY	8-12	12	12	12	15/5	15/5	15/5	12/5	12/5	12/5	12/5
TRAMA RM					25/5	25/5	25/5	12/5	12/5	12/5	12/5
ANESTH STO	2	2	8	8/8	8/8	8/8	8	8	8	8	
PATIENT RM	1.5	1.5	2	4/2	4/2	4/2	2/2	2/2	2/2	4/2	
TOILET RM					10	10	10	10	10	10	10
INTEN. CARE				6/6	6/6	6/6	6/2	6/2	6/2	6/2	
ISOLATION		4	4	6	12/12	12/12	12/12	6/2	6/2	6/2	6/2
ANTEROOM					6/6	6/6	6/6	10/2	10/2	10/2	10/2
LDRP											4/2

(TOTAL AIR/OUTSIDE AIR)

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991
PATIENT CORR					4/4	4/4	4/4	4/2	4/2	4/2	4/2
RADIOLOGY											
X-RAY SURGERY										15/3	15/3
X-RAY D&T		6	6	10	6/6	6/6	6/6	6/2	6/2	6/2	6/2
DARKROOM		10	10	12	15/6	15/6	15/6	10/2	10/2	10/2	10/2
LABORATORY											
GENERAL					6/6	6/6	6/6	6/2	6/2	6/2	6/2
BACTERIOLOGY		10	10	10						6/2	6/2
BIOCHEMISTRY										6/2	6/2
CYTOLOGY										6/2	6/2
GLASSWASH									10/2	10	
HISTOLOGY										6/2	6/2
NUC MED										6/2	6/2
PATHOLOGY									6/2	6/2	
SEROLOGY										6/2	6/2
STERILIZATION									10	10	10
MEDIA TRANS				4/4	4/4	4/4	4/2	4/2	4/2	4/2	
AUTOPSY		10	10	15	15/6	15/6	15/6	12/2	12/2	12/2	12/2
BODY HOLD (NO FRIG)							10	10	10	10	
PHARMACY								4/2	4/2	4/2	4/2

(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	10/10	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

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.

- Select model pathogens for use in testing sampling methods and controls.
- Evaluate control technologies, individually and in combination.
- Evaluate the performance of filtration control.
- Characterize and assess resuspended aerosols.

Once these recommendations were developed, the panel attempted to set priorities for these research needs. There was unanimous agreement that the first three items on the bullet list above were *very important* research needs. The study of microbial ecology was listed slightly lower, as *highly important*. The consensus opinion for the fourth and fifth items on this list was to rate them as *moderately important*; each of these items was rated as a *very important* research need by at least one of the panelists. The last two items on this list were rated *moderately important* by the whole panel.

PRIMARY AEROSOL CHARACTERIZATION

A primary research goal identified by the committee was the characterization of infectious aerosols as they emerge from the source. To validate laboratory studies with test organisms, the carrier particles need to be matched to the real-world particles. Infectious aerosols in health care settings will include sputum and other condensed material besides the viable organism(s). The aerodynamic properties of the carrier particles will affect the settling velocity, residence time in the environment, and the capture velocity needed to remove the infectious particle from an airstream. Other control strategies, such as the efficacy of ultraviolet germicidal irradiation may be affected if the organism is occluded by surrounding mucosal material. Some specific research objectives that were identified are:

- Characterize respiratory emissions from patients.
- Characterize carrier particles from environmental sources such as shower sprays, cooling towers, HVAC systems, etc.

- Characterize aerosolized particles containing bacteria, fungi, and viruses.
- Characterize aerosols generated by medical devices or invasive procedures such as bronchoscopy or laser surgery.

PHYSICAL PROPERTIES

The size, shape, and aerodynamic properties of infectious agents in the environment should be assessed. To develop sampling and analytical methods, one needs to understand the size, shape, and viability of infectious agents. Organisms may transform themselves (size, shape, density) to survive in the hostile aerosol environment (desiccation, ultraviolet exposure, lack of nutrients, and presence of chemicals and disinfectants). Consequently, their aerodynamic properties may be different in the environment than those agents in the laboratory or those immediately after emission from the patient or source. Some specific research objectives are:

- Investigate aerosol size and shape transformations in the environment and *in vivo*, to avoid introducing sampling artifacts.
- Understand how organisms survive as an aerosol, providing insight for control strategies.
- Collaborate with microbial ecologists.

SAMPLING & ANALYSIS

Existing sampling and analytical methods for infectious agents need to be improved and new ones developed. To control exposure, evaluate controls, or identify potentially hazardous conditions, technologies for rapidly and reliably assessing the presence and quantity of infectious agents are needed.

- Develop methods for sampling and analysis for each category of agent, e.g., bacteria, fungi, and viruses.

- Develop sampling techniques that include personal samplers, large volume samplers, and size fractionating samplers.
- Develop techniques to provide rapid detection, optimally producing an instantaneous and continuous monitor.
- Interface air sampling methods with gene amplification (PCR) and immuno-chemical techniques for assessing, identifying, and quantifying airborne microorganisms.

MICROBIAL ECOLOGY

The microbial ecology of the airborne organisms should be studied. Factors that regulate growth, including organisms response to drugs, disinfectants, and ultraviolet light, provide insight into control strategy options. The ability of organisms to survive in sample collection devices may also represent a significant problem. For viable sampling methods, the organisms must maintain their ability to reproduce and grow following impaction, impingement, and possible desiccation on a filter or other sampling surface. Specific research objectives are:

- Explore viability of microorganisms: viability in the source, survival in aerosolization, survival in transport (turbulence).
- Explore microorganisms survival in sampling.
- Collaborate with aerosol physicists.

MODEL PATHOGENS

It may be argued that most of the research objectives identified for control of infectious agents in health care and related facilities depend on the availability and suitability of model organisms to be used in experimental protocols. The model organisms are required to test sampling devices and to assess the effectiveness of control technologies without using the pathogens themselves.

There is a need to identify and select model pathogens for use in testing sampling methods and control technologies. Models for bacteria, fungi, and viruses may be needed. Pathogens of concern that require model organisms include, but are not limited to: *M. tuberculosis*, *Legionella*, *Aspergillus*, and rubella, influenza, varicella , adenoviruses. and measles. While there will be no one organism that will meet the needs of every possible experimental program, sets of candidate organisms can be identified and made available. Some specific research objectives identified to meet this need include:

- Establish selection criteria for surrogates, e.g., growth rate, metabolic and genetic similarity, etc.
- Depending on the nature of the study, identify candidate organisms for TB, but may include: *M. bovis* (BCG), H37Ra, *M. avium*, *M. intracellulare*, *M. terrae*, *M. phlei*, etc.

CONTROL TECHNOLOGY

Most of the other research objectives identified by the Workshop will produce recommendations for improvements in the near and distant future. Research on, or immediate application of existing control technologies may reduce the incidence of infections immediately. To improve on infection controls, research on the effectiveness of various control technologies, individually and in combination, is needed. Control strategies currently proposed include ventilation (local and general), HEPA filtration, ultraviolet germicidal irradiation, and respiratory protection. Efficacy needs to be proved. Some specific objectives include:

- Investigate innovative technologies for control.
- Assess germicidal agents on infectious aerosols (ozone, formaldehyde, hydrogen peroxide, and ClO_2).
- Assess the effects of turbulence and convection on control systems.

FILTER PERFORMANCE

The efficacy of filtration, including HEPA filters, and the use of respiratory protective equipment needs to be assessed. Evaluate the penetration and viability of organisms as they pass through filters. Research objectives include:

- Determine if microbial particles behave differently than normal filter test aerosols, i.e., corn oil (filter penetration).
- For those particles passing through filter materials, determine how their viability is affected by the experience (defined as the ability to reproduce and amplify).
- Evaluate re-aerosolization of microbial aerosols from the collection-side of the filter media during maintenance or when otherwise disturbed.

RESUSPENSION

Assess survivability of infectious agents on surfaces, clothing, bedding materials, etc., which may be contaminated with infectious agents and have the potential to be re-aerosolized. Settled particles could become reentrained by vacuuming or through disinfection or decontamination procedures, or other activities creating a potential exposure. Research should also focus on fungi for aerosolization from surface growth.

RESEARCH RECOMMENDATIONS FOR SOURCE CHARACTERIZATION AND SOURCE CONTROL

INTRODUCTION

In the case of airborne infections, the major source of exposure (with some exceptions to be discussed below) is a person, usually at a health care facility. The process that produces the "airborne infection" is also very dynamic. Levels of production appear to increase and decrease with little predictability, unlike many manufacturing processes. Despite this unpredictable nature, infection control personnel have been relatively successful in the past at controlling exposure to airborne infections in health care facilities. Dr. Melius believes that most of the success in this area does not result from the usual techniques used in occupational health such as exhaust ventilation, personal protective equipment, etc. Rather, our colleagues in communicable disease and infection control have achieved this control by identifying potential sources of infection and isolating this potential source. This source identification and control has been a major accomplishment and should be recognized as the key step in controlling transmission of tuberculosis in health care facilities.

A few terms that were discussed and defined up front included health care facilities, related facilities, workers, and worker-acquired infections. The term "health care facilities" includes, but is not limited to, hospitals, clinics, group practices, private physician's offices, homes (home care), community and medical laboratories. The term "related facilities" includes, but is not limited to,congregate living quarters, corrections facilities (jails, prisons, and holding areas), autopsy/morgue facilities, substance abuse centers, transportation vehicles, laboratories, social service centers, nursing homes, and medical waste facilities. The term "worker" includes, but is not limited to, health care workers (medical and reception/registration staff), emergency medical services personnel (first responders), corrections personnel, social

workers, housekeeping staff, laboratory workers, facilities personnel, volunteers, and students. Following a brief review of Dr. Eickhoff's plenary paper on airborne infection, the panel discussed which organisms (bacteria, fungi, and viruses) associated with airborne nosocomial infections have been implicated in occupatianally acquired airborne infections. The following organisms have been implicated as potential occupatianally acquired infections in workers who are non-immunocompromised: respiratory syncytial virus, Varicella-zoster virus, Parvovirus, *Mycobacterium tuberculosis*, and *Legionella pneumophilia*. Given the current importance of tuberculosis, particularly multidrug-resistant tuberculosis, a majority of the discussions and recommendations focused on tuberculosis transmission.

Research recommendations for source characterization and control are the result of in-depth discussions by this scientific panel. While some of the recommendations may overlap those from other panel sessions, all are included in this summary. The panel developed five general areas of research and program control recommendations:

- Identification of infectious sources
- Epidemiology and surveillance studies
- Engineering and procedural controls and work practice modification
- Training and education
- Recommendations not otherwise classified

The recommendations have been subdivided into three major priority groupings: highest priority, high priority, and priority.

IDENTIFICATION OF INFECTIOUS SOURCES

The major source for the transmission of airborne infections in health care and related facilities is infected persons. Bacteria or viruses may be exhaled as the person talks, coughs, or sneezes. Microbial contamination of ventilation systems, while a contributing factor in potential nosocomial infections in

immunocompromised persons, has not been commonly reported in health care workers as a result of work-related exposures. Thus, prompt identification of infectious individuals is of utmost importance. Following are the Panel's recommendations:

- Develop rapid and accurate (specific and sensitive) methods for diagnosing infections capable of being transmitted by the airborne route. Develop real-time "TB breath analyzer." *Highest Priority.*

- Develop strategies for the early triage, identification, isolation, and diagnostic testing (e.g., acid-fast bacillus [AFB] smears, polymerase chain reaction [PCR], etc.) of individuals who have infectious TB. *Highest Priority.*

- Evaluate sensitivity, specificity, and variability of current purified protein derivative (PPD) preparations and protocols for the identification of persons infected with *M. tuberculosis*. *Highest Priority.*

- Develop improved skin test reagents (or other methods), for *M. tuberculosis* (increase sensitivity and specificity of existing tests), and for the identification of infection with Mycobacteria other than tuberculosis. *High Priority.*

- Develop a better understanding of the potential for infection from organisms capable of airborne transmission that may remain viable for long periods of time on surfaces, and evaluate appropriate methods of disinfection. *Priority.*

EPIDEMIOLOGY AND SURVEILLANCE STUDIES

The following recommendations relate to the study of transmission of various infectious diseases as they spread and the factors that may contribute to disease transmission.

- Evaluate the adequacy of infectious disease surveillance systems (i.e., identification of patients known to be infected) in local and state health departments. In particular, develop

procedures to ensure the appropriate institutions are notified so that persons with infectious tuberculosis are immediately identified. *Highest Priority.*

- Establish a prospective surveillance system for tuberculin skin test conversions in health care facilities (e.g., possibly National Nosocomial Infection Control System-based [NNIS-based]). This system should include assessment of controls already in place and their effect on skin test conversion rates and the clinical course of skin test converters. *Highest Priority.*

- Conduct follow-up studies of exposed workers to better understand the sources of airborne infections and the efficacy of current control procedures. *Highest Priority.*

- Conduct epidemiologic studies of worker tuberculin skin test conversions in "related facilities" to identify the risk of acquiring TB infection in these settings. *High Priority.*

ENGINEERING AND PROCEDURAL CONTROLS

Many of the source control methods used to prevent airborne transmission of infectious diseases involve procedural as well as engineering methods of controlling exposures. Although the focus of this panel was source characterization and control, this panel did engage in a limited discussion of respiratory protection. This discussion and the recent CDC draft guidelines resulted in one of the recommendations contained in this section. In addition, recommendations for research into engineering and procedural controls follow:

- Evaluate existing and develop novel control methods for special high risk procedures such as sputum induction, bronchoscopy, patient transportation, etc. which may involve the utilization of specialized ventilation or local exhaust

systems. Parameters to be evaluated include application, performance, placement, and maintenance of ventilation systems and other controls. Employee training programs, standardized test methods for *in situ* evaluation of controls, and user acceptability criteria should be developed. *Highest Priority.*

- Evaluate efficacy of recirculation units (i.e., in-duct air filtration and ultraviolet germicidal irradiation [UVGI]) in preventing and controlling airborne tuberculosis transmission via field evaluations and epidemiologic studies. Develop performance, placement, maintenance, employee training, user acceptability, and evaluation criteria (via laboratory and field studies) for these units. *Highest Priority.*

- Evaluate auxiliary exhaust units (i.e., in-duct or in-room, ventilation systems used to augment general ventilation) via field evaluations and epidemiologic studies. Develop performance, placement, maintenance, employee training, user acceptability, and monitoring criteria. *Highest Priority.*

- Develop performance criteria and testing protocols for portable, stationary, and in-duct high efficiency particulate air (HEPA) and ultra low penetration air (ULPA) filtration units (e.g., using criteria set forth in the National Sanitation Foundation Standard Number 49, Class II (Laminar Flow) Biohazard Cabinetry as a model [NSF 49] or other applicable standards). *Highest Priority.*

- Evaluate airflow patterns within the rooms and their impact on local variation of infectious aerosol concentration within the rooms. Parameters to consider include airflow rate, temperature, relative humidity, initial concentration, equipment in rooms, location of supply/exhaust, configuration of rooms, and location of in-room HEPA filtration and dynamic UVGI units. *Highest Priority.*

- Develop a national respirator task force to discuss and make recommendations on the types and use of respirators by patients, health care workers and visitors. The major focus of the task force should include acceptability issues, compliance, knowledge of respirators, worker training, and respirator designs. The efficacy of using surgical masks or valveless respirators by infectious tuberculosis patients as a source control should also be evaluated. The proposed CDC guidelines recommend the wearing of a surgical mask by the patient outside of the tuberculosis isolation room. A workshop similar to this one should be conducted to develop a national research agenda on respiratory protection for workers exposed to infectious aerosols or droplets. *Highest Priority.*

- Evaluate performance and provide information on available filters and filtration systems. Issues to be addressed include bioaerosol penetration (both filtration efficiency and passive transport through moist filter material), amplification of microorganisms in the filter material, and viability of microorganisms on and within the filter material for extended periods. *High Priority.*

- Evaluate personal safety and efficacy issues of UVGI disinfection of air (i.e., upper-air and in-duct irradiation). *High Priority.*

- Evaluate the adequacy of the Wells-Riley equation for estimating the risk of acquiring tuberculosis infection and modify the equation, if necessary. Use this equation to assess the effectiveness of different control mechanisms in removing infectious droplet nuclei from room air. *Priority.*

- Conduct hazard assessment of medical waste disposal workers at health care and medical waste disposal facilities. *Priority - minority opinion.*

TRAINING AND EDUCATION

Training and education are important factors in an infection control program. Evaluation and revision of current materials and techniques are needed to meet the objective of preventing the transmission of all infectious agents.

- Develop curricula to provide multi-disciplinary training to institutional staff with responsibilities for infection control programs (including tuberculosis control), including practitioners in infection control, industrial hygiene, and facilities engineering, and provide training on a regional basis, as needed. *Highest Priority.*

- Develop, evaluate, and disseminate a training program on infection control (culturally and educationally appropriate) for patients, clients, inmates, workers, and others. Different programs will be required for different types of facilities. *High Priority.*

RECOMMENDATIONS NOT OTHERWISE CLASSIFIED

This final section includes recommendations which did not fall under one of the other four major areas of research. Issues which need to be addressed include special considerations of individuals (i.e., individuals covered under the Americans with Disabilities Act [ADA]), compliance with infection control procedures, and overall management of an infection control program.

- Evaluate factors related to patient and other's compliance with isolation and other infection control procedures, identify potential barriers to compliance, and develop strategies to improve compliance. *Highest Priority.*

- Determine lowest achievable risk of occupationally acquired tuberculosis infection, as measured by tuberculin skin test conversion, adjusted for varying prevalence of tuberculosis infection in the population. *Highest Priority.*

- Develop a mechanism to reach agreement on acceptable risk of acquiring occupational airborne infections (especially tuberculosis). *Highest Priority.*

- Develop guidelines for reasonable accommodation, as defined by the Americans with Disabilities Act (ADA), for immunocompromised workers potentially exposed to infectious aerosols (including *M. tuberculosis*). *Highest Priority.*

- Develop an understanding of the indicators of susceptibility and disease progression for immunocompromised workers to facilitate their personal decision-making regarding the use of protective measures, etc. *High Priority.*

- Study the institutional and organizational factors that impact upon the implementation (or non-implementation) of sound airborne infection identification, prevention and control programs. *High Priority.*

RESEARCH RECOMMENDATIONS ON BUILDING DESIGNS

INTRODUCTION

It is imperative that consideration to specific issues be addressed before a national research agenda can be established and implemented. These issues include building designs that are based on appropriate risk assessment, prevention of hysteria and over-reaction, consideration of humanistic concerns, building designs by multi-disciplinary teams, appropriate public and private sector educational programs, uncomplicated system designs and maintenance programs, the development of standards as performance criteria, and building construction incorporating system maintenance concerns.

Building and system designs should be based on comprehensive risk assessment and scientifically proven control techniques. In this way, hysteria and over-reaction can be assuaged without minimizing the significance of tuberculosis and other airborne diseases. There should be an understanding where areas of exposure occur, an understanding of the resultant risk to staff and patients, an appreciation of the differing needs of inner city centers versus those in rural communities, and more meaningful methodologies and approaches than are currently being used (i.e., the "one isolation bed per thirty general medical-surgical beds" cook book ratios). Caution should be exercised with the wholesale application of black box technologies (i.e., ultra-violet germicidal irradiation and portable high efficiency particulate air [HEPA] filtration devices) whose efficacy are uncertain.

Design criteria must incorporate humanistic concerns. Most importantly, the disruption between the health care worker and the patient should be minimized. Environments should include factors to mitigate potential discomfort and deprivation from hard surfaces and equipment noise. Designs should respond to the ergonomic needs of patients and staff; infection control barriers and measures should not make patient care or interaction physically cumbersome. It is important to recognize the special needs of select patient populations. Specifically, attention must be paid to patients with longer lengths of stay (possibly up to one year or more), to patients who are involuntarily confined, and to those patients from special populations (i.e., mental health or prisons).

The design of new health care facilities (or the renovation of existing ones) must be the coordinated effort of a multi-disciplinary team. The design team should include engineers from the start of the project (including the conceptual stages), through the architectural design, and to the final commissioning of the building and systems. Additionally, the team should include representation from the infection control service to help educate other members of the team on the need for control measures, to evaluate proposals, and to select the most appropriate methods of control. Every member of the team should understand all the project objectives.

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.

RECOMMENDATIONS

- Develop immediate interim methods for improved worker and patient protection until new construction, renovation, and/or initiatives are developed for medical centers and related facilities such as homeless shelters, ambulatory care, methadone clinics, etc.

- Development of methodologies to calculate the number of inpatient acute and intensive care infectious isolation rooms on a regional health planning basis and hospital or network-wide. Also methodologies need to be established to identify those:

  Hospital-based ancillary services needed to support that population including diagnostic and treatment facilities.

  Alternate care delivery sites such as schools, shelters, residential treatment centers, etc., to support that population.

- Develop criteria and programming needs for the layout and location of infectious isolation and related facilities such as: Emergency Departments, Clinics, Imaging, Oral Surgery/ Dental, Sputum Induction/Pentamidine, Administration, Morgue/Autopsy Suite, Surgery and Recovery, Endoscopy, Respiratory Therapy, 23-Hour Unit, Prenatal, and Laboratory. For *each* of these areas:

  Specific items to consider are (but not all-inclusive): staffing, additional space needs, and location of rooms to ancillary services.

  Develop specific programming and design criteria considering the physical layout and related equipment requirements. Items to consider are (but not all-inclusive): Furniture, finishes, square footage, sealing of room, operable versus fixed windows, monitoring of airflow, and equipment, etc.

Develop space criteria for appropriate mechanical system maintenance, repair, and replacement.

Develop coordinated regulations considering airborne infection controls, fire and life safety, energy conservation (potential BTU tax), and the Americans with Disabilities Act.

Balanced against health care risks, determine the need for "black box" technology (e.g., UV and "in-room" HEPA units) and other methods for air disinfection and contaminant removal. If affirmed, establish design criteria for proper installation and operation.

Specific to isolation suites (consider the necessity for providing an anteroom):

Are airlocks required to maintain negative or positive pressure?

Is the space necessary as a work and storage area in which to practice infection control?

If an anteroom is provided, can it be shared between two infectious isolation rooms?

Assess the need for positive (out) airflow from the room. (Are reversible systems recommended?)

Establish strategies for converting existing buildings to meet the criteria and programmatic needs of protecting health care workers and patients from airborne infections.

Study the effect on health care and/or social service workers with prolonged or repetitive contact with high risk clients. If determined necessary, develop design and programming criteria for special considerations for that population.

- Research the probability of workers and clients acquiring airborne infections in overcrowded conditions (e.g., places of assembly, transportation, homeless shelters, day room, etc.).

- Determine the appropriate design criteria and technology for areas where sputum induction, administration of aerosolized medications, and other high risk procedures are performed, such as booths, specialized rooms or enclosures (bronchoscopy and pentamidine administration).

- Develop the performance criteria for designing facilities for patients having a long-term need for treatment or isolation (e.g., need for living space, recreational facilities, movement around the facility):
  - Patients in "non-compliant" detention
  - Patients where isolation is required
  - Correctional facilities, e.g., jails, prisons, and holding facilities

- Develop design criteria for prolonged contact waiting spaces (e.g., initial patient screening, emergency department holding areas, public waiting spaces, etc.).

RESEARCH RECOMMENDATIONS FOR VENTILATION DESIGNS

INTRODUCTION

Effective control of the spread of airborne infectious diseases in health care and related facilities will necessitate the use of a variety of techniques including ventilation. Ventilation techniques for maintenance of indoor environmental quality have some application. However the unique characteristics of airborne infectious diseases in the health care setting such as lack of quantitative information on contaminant generation, low contaminant levels, mobility of the infection source, and difficulty of idenfication require that new ventilation techniques and application criteria be developed.

Research recommendations for ventilation techniques for controlling the spread of *M. tuberculosis* in health care facilities were developed by a panel of experts with experience in control of infectious diseases in health care facilities. The panel began its discussion following a plenary presentation on health care ventilation by Richard Hermans and Andrew Streifel. The following research topics should be addressed in developing ventilation design and operating parameters:

- Pathogen generation rates and concentration control levels
- Identification of ventilation rates
- Distribution of general ventilation airflow
- Local exhaust ventilation
- Filtration
- Containment
- Maintenance
- Performance monitoring
- Ventilation control system design
- Side effects of engineering controls
- Role of ultraviolet irradiation in infection control
- Sampling and testing methods
- Interdisciplinary communication
- Comprehensive control study

DEVELOP VENTILATION DESIGN AND OPERATING PARAMETERS

- Pathogen generation rates and concentration control levels—the application of effective control technology requires knowledge of the level of contaminant being generated and a concentration level to control to. These levels are not well known for airborne infectious organisms and need to be determined.

- Identification of ventilation rates

- Distribution of general ventilation airflow—research is needed in several areas associated with general ventilation.

  The Wells-Riley equation provides the probability of infection using a mathematical relationship between contaminant generation rate, room ventilation rate, the number of infected patients, pulmonary ventilation rate and time. Research is needed to determine the feasibility of utilizing this equation to establish appropriate ventilation rates.

  Currently available criteria for general ventilation in the health care facility are primarily based on comfort considerations. Airflow rates are provided primarily for hospital settings. The effect of airflow level in reducing contaminant levels in a space needs research.

  Airflow distribution is not addressed other than the recommendation for air to flow from areas of "higher" contaminant concentration to "areas of "lower" contaminant concentration. Very little information is available for health care areas other than the hospital. Detailed information is needed on the effects of distribution such as comparison of displacement vs. dilution ventilation.

It is noted that the above areas can be effectively researched as individual entities but effective control will necessitate some combination of all three.

- Local exhaust ventilation—local exhaust can consist of open exhaust hoods placed near a patient, patient enclosures and portable cleaning devices. Research is needed to apply the open type hoods to treatment procedures such as bronchoscopy. Research is needed to determine efficacy of portable cleaning devices and to develop standards for maintenance and operation of both patient enclosures and portable cleaning devices.

- Filtration—filtration can be effectively used to remove contaminants from air exhausted from rooms, patient enclosures, portable cleaning devices, or other local exhaust hoods. Research is needed to determine application and effectiveness of filtration for various infectious disease organisms. In addition research is needed to evaluate the safety aspects of filter maintenance including determination of the viability of infectious disease organisms trapped in the filter housing media and procedures for safe removal, handling and disposal of the used filters.

- Containment—containment by use of isolation can be effective if properly utilized. There are however questions regarding the proper airflow balance in a room to achieve adequate levels of negative pressure and the need for ante rooms (and ante room airflow balance) to prevent escape of contaminant from the room during ingress and egress. Research to evaluate these questions and to develop criteria for isolation room negative pressure is needed.

- Maintenance guidelines and performance monitoring—poor maintenance and lack of performance monitoring criteria are common problems with ventilation systems and are often the cause of poor system performance. There is a need to develop

maintenance guidelines focused on health care ventilation systems which can be readily implemented to prevent system breakdown. There is also a need for the development of system monitoring techniques which can identify and warn of potential system performance degradation.

- Ventilation control system design—the overall operation of a facility ventilation system is dependent on maintenance of airflow rates and area pressures throughout the entire facility. Maintaining these parameters in proper balance is necessary to achieve the desired ventilation condition. Review of the system controls necessary to achieve and maintain this balance for the unique conditions of the health care setting is recommended.

- Side effects of engineering controls—the application of engineering controls (such as patient enclosures) may have adverse effects on the patient and may result in rejection of the control. It is recommended that a study of the side effects of existing and new engineering controls be made to identify acceptance problems and to recommend corrective procedures which will aid in acceptance of the control.

- Role of ultraviolet irradiation in infection control—ultraviolet irradiation has long been utilized as a control for airborne infectious diseases in the health care setting. There are, however questions regarding its efficacy and safe operation. It is recommended that a study be conducted to evaluate the efficacy of UV in killing airborne infectious organisms and to develop parameters (dose response) to permit its effective application. Recommendations also need to be developed for safe operation and maintenance.

- Sampling and testing methods—available sampling and tests methods for a wide range of airborne infectious organisms are for the most part not suitable for field sampling and for the evaluation of control performance. There is need to develop

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

- Interdisciplinary communication—many of the control strategies and research areas necessary for the health care area are common with other areas including both the industrial and indoor environmental areas. Transfer of this information between areas has not occurred to any extent. It is recommended that the feasibility of a health care control technology data base be investigated. 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. While the effectiveness of an individual control may be determined in a laboratory setting, its individual contribution in practice may be difficult to quantify. It is recommended that a control study 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).

SYNOPSIS

MORTON LIPPMANN — SYNOPSIS

It has been an interesting and rewarding three days. I've been very gratified at the cooperative spirit at this Workshop. The preceding Panel summaries were done so well that we now have good lists of the critical questions. That was our primary task, and it has been well met.

For the Workshop as a whole, I thought I might prepare a collective report card, showing how well we have met the goals of the Program Committee and served the national need. I will then go through some other items of a more general nature. I will review our accomplishments, and the assignments we should take away from this exercise for future activity. Clearly, if we don't carry-on what we started here, a lot of the energy and effort that's gone into this Workshop will have been wasted. Finally, I will deal with some generic issues which, in my personal view, arise from these Workshop discussions.

It is clear that the quality of the Panel members' homework was excellent. We had very good state-of-the-art papers, which enabled the Workshop process to move ahead expeditiously. My observation in visiting each of the individual panels was that the level of effort was certainly high, as was your ability to work together and share the knowledge that each of you, as a specialist, brought to each panel. The topic of "Seamanship" was put in the report card on the basis of Dick Lemen's opening remarks quoting Oliver Wendell Holmes to the effect that the important thing is that we know which direction to sail, and to move in the right direction in a difficult and stormy sea. In this regard our report card item "Advancement to the next level" warrants a good grade. The critical issue for the future is whether we are going to work effectively on our follow-on activities.

What have we accomplished? Collectively, we have a better appreciation for the nature and extent of airborne transmission of infections, the role of facility design and maintenance in airborne

disease transmission of infections, the control options, and, to some degree, the performance of our tools, i.e., source control, local exhaust ventilation, air purification, and controlled distribution of airflow. We have compiled a comprehensive list of research needs, and in some but not all cases, we have identified those for which research in the short term can help us address the problems that confront us today. We also have identified longer-term research needs.

In addition, we have identified critical generic needs. Among these are a need for improved means of communicating available knowledge. It's clear from our discussions that our past efforts to reach the key target communities have not been as effective as they need to be for effective control of airborne transmission of disease. Specific recommendations include the preparation of manuals and guidelines for distribution to the key target communities. Perhaps the highest priority need is that of the maintenance community, because of the needs both to protect them, and to enable them to protect others. They are both a population-at-risk and a population that affects risks. The manuals of procedures must be in language accessible to maintenance personnel, and must address what to do under normal conditions, as well as under emergency procedures when things go wrong. Normal conditions refer to controlling air pressures, flow rates and directions. When the air handling systems fail, or other hospital emergencies take place, it is important to specify what the maintenance people should do in order to protect the workers and the patients.

Guidance documents also are needed for normal and emergency conditions for direct patient contact personnel; i.e., the nurses, medical technicians, and physicians. Finally, the administrative and custodial personnel, who have only indirect contact, need to have guidance for protecting themselves. On the administrative side, they also need to see to it that other personnel receive all the protection that is feasible.

We, collectively, have a critical need for a consensus building. One task is to assure follow-up of the initiatives from this

Workshop. My sense is that almost all of you agree that this has been a successful start in a process to build consensus. What else can CDC/NIOSH do in particular? What can other groups do? What can we do individually to take advantage of where we are? We can address regional groups on the need for workshops and seminars. We also can establish and maintain contacts with our professional colleagues, as well as with each other, in order to keep up some momentum for further progress.

What are our assignments? What can this group do, and what can we encourage others to do? One recurring theme in all of the panels that I visited was a limited access to relevant unpublished knowledge, especially the personal knowledge of experienced colleagues. It seemed to me much of that valuable personal knowledge and experience is publishable, at least as technical notes. The *American Industrial Hygiene Association Journal* and *Applied Occupational and Environmental Hygiene* have sections specifically for Applications Notes, which don't have to meet the criteria applicable to a full research paper. Based on some of the discussions we have had here, perhaps each of you could go back to your files and find something that you could add to the literature. If so, try to get it into the published literature, at least as a technical note. If more such information was generally available, we wouldn't have to get so many individuals together in a room in order to begin to assemble useful guidance. Such informal exchanges will always be incomplete, because only a limited number of people with appropriate knowledge will be present in that room. Publishable technical notes can be based on population-distributions of exposures, conversion rates, disease incidence, and influence of the various factors that affect them. On the efficacy of engineering controls, there clearly was a lot more anecdotal data that was known to the people in the room, but not published, than should be the case. The same could be said for data on the efficacy of administrative and personal exposure controls.

I therefore challenge each of you to do what you can to add to the body of literature and to encourage others to do the same. I also challenge you to encourage further communication not only with

your colleagues, but with those people who are at risk or affect risk. My comments on the generic research issues more or less follow from the nature of the format for the panels.

One major issue discussed was the analytical capabilities for exposure evaluation in terms of both sampling and analysis. Another major issue that was discussed, but not resolved, is how much control is needed for disease prevention. This refers to controls, not for their own sake, but for the primary purpose of preventing airborne transmission of disease. We recognized a need for a higher level of control when we're dealing with compromised individuals, a major consideration in health care facilities. We shouldn't be satisfied if we merely protect the healthy individual, because there are too many people in current society, especially in the hospital setting, who are compromised.

Cost containment is clearly a major issue of the day. Another is risk assessment, to provide a basis for risk management decisions. Since there isn't an infinite supply of either research dollars, or dollars available for addressing the control needs, we must come to grips with what is an acceptable level of control at a practical price. In this regard, the "TLV" concept was discussed. Many people criticize the occupational threshold limit values as being less than satisfactory because they only provide a basis for protecting "nearly all" workers. Some segments of society believe that there should be no limitation on how far we should go to protect the most sensitive individuals. In practice, we are going to have to make some decisions about how far along that continuum we are willing to commit our own and the public resources.

What is the extent of control that is achievable? For the near future, resource constraints will necessitate a focus on retrofit and renovation, rather than construction of new facilities.

What is the extent of control that can be achieved by patient isolation, and how far can we go in this area because of the technical limitations or ethical constraints? What about the applications of emerging technology? In his Panel Summary,

Ben Liu said we shouldn't be fully satisfied until we have direct reading instruments that tell us not only the concentration of TB bacteria, but whether they're dead or alive. Clearly, he wasn't suggesting that as a goal that was achievable anytime soon. However, if we don't have long-range targets in mind, we won't make much progress.

What can we do in terms of the emerging control technology? Clearly, there are targets of opportunity in this area, since the control engineers have increasing capabilities because of the nature and low cost of microprocessor controls for ventilation systems.

My topic outline for these concluding remarks includes "telemedicine." This was stimulated by a front page story of yesterday's *New York Times* (Thursday, July 15). It contained "blue sky" speculation about the role of video in the hospital and health care setting. The high definition equipment now available (and the accessibility of radiologic and other records) makes it possible for many of the specialists involved with patients to do their thing without having to travel to the hospital and without having to be exposed to the patient. We can't always isolate the patients so completely that they never see any caregiver. On-the-other-hand, we can certainly minimize the unnecessary contact between accessory medical personnel and the infected patient by utilizing this new technology.

In closing, I want to note the skill and dedication provided by each of the members of the panels and the contributing members of their audiences in coming up with well-crafted and reasonably comprehensive research agenda items. Even when the issues couldn't be framed in terms of research themes and topics, the discussions did at least get the questions out on the table for the research community. Knowing what issues are important can help to focus research grant applications to NIH and other funding agencies.

I am certainly pleased with the outcomes of this pioneering effort. It has helped to stimulate interdisciplinary cooperation. I endorse the recommendations that Rick Hermans presented about seeking

mechanisms to establish an interdisciplinary oversight committee to help us cross agency borders and to keep contacts with those here and others. We need to find a mechanism, and a home in one of the government agencies, for establishing the kind of data base that he was talking about for engineering data. Let's build upon his Panel's recommendation, and seek to establish a data base that covers the aspects covered by the other Workshop panels as well.

I personally thank you for everything that you all have done individually and collectively. I know my co-chair, Phil Bierbaum, also wants to thank you, and he has some closing remarks which follow.

PHILIP BIERBAUM — SYNOPSIS

What I will do for my summary is to try and identify from the panels' recommendations some "hot topics" that Dr. Lippmann and I will use in compiling the Executive Summary for these Proceedings. So bear with me as I go through and highlight a couple of key words from the four panels.

It is interesting that across these panels many topics come up over and over, even though we had different sets of experts on each of the panels. These topics are (1) sampling methods; (2) effectiveness of control technologies; (3) characterizing aerosols; (4) survivability of infectious agents; (5) accessing the size, shape, and aerodynamic properties of infectious agents; (6) microbial ecology; (7) sampling and analytical methods; (8) evaluating control technologies; (9) efficacy of filtration; (10) methods for diagnosing infectious transmitters; (11) control methods for special procedures within hospitals and other settings; (12) strategies for early triage; (13) evaluation of recirculation units; (14) evaluation of total exhaust units; (15) evaluation of filtration units; (16) evaluating airflow patterns; (17) patient compliance; and (18) multi-disciplinary training. A lot of the recommendations that were developed dealt with engineering controls. However, in the Source Characterization and Control Panel, it was recognized that there are many "administrative" procedures that are needed which are not defined as "engineering controls."

I believe that a major issue we have to recognize is that it's not just health care facilities but other related facilities (e.g., correctional facilities and social service facilities) where there are also exposures for workers. Filters and filtration systems, efficacy of disinfection, indicators of susceptibility, validating the Wells-Riley equation also seem to be very important for these workplaces. Another issue that was raised in the panels is that we need to worry about exposure to all workers in these facilities, from maintenance workers to the health care professionals. We want to deal with all workers, not just "health care workers."

An extremely important issue that was raised is that there is an immediate need to deal with developing sampling and analytical methods, and the fact that we are not just trying to develop a research agenda, but that we need to develop control solutions now. Methodologies to calculate the number of inpatient isolation and intensive care rooms; and how to design intensive care rooms, isolation rooms, surgical suites, emergency rooms, etc. are extremely important in geographical locations that have high risk populations. Coordinated regulations, which are consistent for these design criteria, are one of the most important issues that we can help solve throughout our public health and health care systems. We have recognized this at CDC in our efforts to revise the 1990 CDC "Guidelines for Preventing the Transmission of Tuberculosis in Health Care Settings."

We need to understand the usefulness of anterooms; we need criteria for converting existing buildings (which is extremely important for inner city health care facilities); we need to develop design and programmatic criteria for special populations, (e.g., immunocompromised workers and patients) and for special medical procedures (e.g., administration of aerosolized medications); we need design criteria for waiting spaces (which is extremely important because we don't know who is infected in these areas); and we need design criteria for social service areas, homeless shelters, etc.

We need to understand the efficacy of dilution ventilation, airflow patterns, and filtration units. We talked about the need to develop a manual as we have in the industrial hygiene community for industrial ventilation. We need a manual that includes maintenance procedures. We need standard methods for sampling and analysis. Also, as Dr. Lippmann mentioned, we need a database of scientific and "common sense" solutions.

That is pretty much a summary of the "hot items" that I heard coming up over and over.

To repeat for emphasis, it is a very important for us to understand and utilize the expertise found in the infection control practitioner community, the occupational health community, and the engineering/architecture community (which is different than the industrial hygiene community) and to understand how we can work together to solve this workplace problem. This whole issue of collaboration across these groups is unbelievably important because of resource limitations and the need to eliminate duplication of effort.

We have to understand that we do need simple solutions now, in addition to the development of a short-term and long-term research agenda.

As Dr. Lippmann pointed out, we know so much from other arenas in occupational safety and health; we know so much as individuals and groups, but the information is not getting out—it is not being published. What are these case studies about, what does work, and what does not work?

I appreciate everybody that came and helped us at the workshop. We hope that we can develop some momentum from the Proceedings and the interactions that have taken place at the workshop. It is often very difficult, because we go back and start working on other things, but we do have a goal to use this workshop to develop initiatives, to develop a better collaborative approach.

I want to thank Dr. Lippmann as my co-chair and as the individual who helped generate the incentive for the workshop with Dr. Millar last year about this time at the Boston industrial hygiene conference. I want to pay a special note of thanks to our keynote and plenary speakers. I know it is difficult to write such papers, and they did give us a good starting point. Thank you Dr. Eickhoff, Mr. Wheeler, Dr. Cole, Dr. Melius, Ms. Burns, Mr. Hermans, and Mr. Streifel. I want to thank the Panel Chairs and Rapporteurs, Dr. Ben Liu, Mr. Frank Hearl, Dr. Jane Lipscomb, Mr. Paul Jensen, Mr. Doug Erickson, Mr. Ken Martinez, Mr. Bob Hughes, and Mr. Rick Hermans. It always is a difficult task to pull all the discussions

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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