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BIOLOGICAL AGENTS – CONTROL IN THE OCCUPATIONAL ENVIRONMENT

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INTRODUCTION

Microorganisms such as molds and bacteria are normal inhabitants of the environment; they exist in the soil we walk on, in the air we breathe, the water we drink, and even the food we eat. The saprophytic varieties (those utilizing the organic products of other organisms, living or dead, as a food source) generally predominate. Under the appropriate conditions (optimum temperature, pH, sufficient moisture, and available nutrients), saprophytic populations of bacteria and molds can increase in number, or amplify. In the air, they can exist as discrete particles (e.g., as individual fungal spores and bacteria, or their aggregates). These organisms can also aggregate, attach to other particles, form aerosols, deposit on surfaces or growth substrates. Many microbial species have been documented to tolerate various environmental extremes of temperature and pressure allowing them to acclimate even to the most harsh conditions. Certain bacteria, called extremophiles, have been identified in the lower depths of the ocean growing amidst intense volcanic activity. Mycobacteria have been found in mummified tissues. It is clear that microorganisms (fungi and bacteria) are ubiquitous occupants throughout all of the diverse environments of this world and are continual companions on the roads that we travel.

Many species of microorganisms are beneficial to, if not a necessary part of, the environment and to our very existence. Saprophytic molds and bacteria are composters of organic material and are essential actors in the carbon and nitrogen cycles. Many essential nutrients are recycled through microbial actions. Microbial flora in our gastrointestinal tract aid metabolism and help protect us from pathogens.

Humans have made use of microbes over time. Yeasts have been used for millennia to produce alcoholic beverages and to leaven bread. More recently, the metabolic systems of specific microbial populations have been used to produce pharmacologically important products (e.g., penicillin and citric acid), food products (e.g., amylase), and a number of other chemical

agents. Unique uses of the microbial community include the application of bacterial species in the decontamination of hazardous substances (i.e., oil spills in the ocean) and as an insecticide (i.e., *Bacillus thuringiensis*) to control cabbage worm, cotton boll worm, and chicken louse. Our everyday encounters with most members of the saprophytic community generally do not pose a significant health risk to the immunocompetent worker population (healthy adults). However, select occupational environments present unique exposure concerns due to the nature of the microorganisms encountered, the microbial concentrations observed, and the susceptibility of the exposed population. Within the healthcare industry, attention has focused on human infections or infectious agents of which the obligate parasites and facultative saprophytes (including the primary pathogens and opportunistic pathogens) are the primary concern (Burge, 1989). In recent years, bioaerosols (the term given to microorganisms and/or their products entrained in/on airborne particles) have become prominent safety and health issues in agriculture, biotechnology, industrial settings, and more recently, the non-industrial indoor environments. Much of the concern for these types of exposures has focused on the ability of certain microbiological species to elicit allergic or inflammatory responses in susceptible individuals.

THE BASICS

The practice of industrial hygiene is based on the ability of an investigator to *anticipate*, *recognize*, *evaluate*, and *control* exposures to hazardous agents (chemical, biological, and/or physical) in the occupational environment. Hazard recognition may include the identification of significant agents from past exposures and the anticipation of exposures to agents which may be infectious, toxigenic, or allergenic. The investigator must have a fundamental understanding of the physical, chemical, and toxicological properties of the agent in order to accurately predict the route and extent of the exposure, and resulting health effects. Additionally, a comprehensive knowledge of the suspect etiologic agent will lead to the selection of appropriate evaluation tools and recommendations for control strategies that could prevent future exposures. For example, investigators from the Centers for Disease Control and Prevention (CDC) were requested in 1996 by a district health department for assistance in evaluating an unusual increased incidence of unexplained pneumonia within the community (CDC, 1996). Thorough epidemiologic study of the community and positive diagnosis of legionellosis among three individuals in the population focused investigation efforts on a large home-improvement center. Environmental sampling resulted in a positive culture for *Legionella pneumophila* collected from a whirlpool spa filter that was a positive match for two of the three legionellosis cases. Control recommendations included regular inspection, maintenance with biocides, and routine filter changes or decontamination. A similar episode occurred at a large floral show in the Netherlands in February 1999 resulting in 242 cases and 28 fatalities (Boshuizen et al., 2000). In this instance, molecular biology based assessment methods allowed identification of the source within two days, thus reducing the severity of the epidemic.

In some occupational settings, these characteristic properties of agents causing illness may not be clearly defined. In the indoor environment (e.g., office buildings), exposures to reservoirs of toxigenic fungi have been associated with the development of occupant disorders including respiratory and central nervous system effects (Johanning et al., 1996; Hodgson et al., 1998). However, a specific organism or toxigenic product could not be exclusively linked with the identified health effects. Without the recognition of a specific etiologic agent, decisions regarding the remediation and subsequent control of affected areas in these situations is complicated. The potentially toxic nature of the suspect agents suggests a conservative approach that includes the complete removal and decontamination of all fungal reservoirs using rigorous isolation strategies and personal protective equipment.

The evaluation phase of an investigation provides qualitative and/or quantitative data to support or refute the hypothesis of occupational exposures to the suspected agent. A series of hypotheses, postulating the presence of an agent (or agents) of putative illness, a pathway for potential exposure, and evidence for exposure must be framed to support a sampling strategy (Macher et al., 1999). The data collected as a result of the investigative plan can range from documentation of safety and health deficiencies observed during a walk-through investigation to the results of environmental (bulk, surface, and/or air) samples analyzed for microbial content. The collected data are then evaluated to appropriately estimate the risk to the worker population and to suggest possible control methodologies. There may exist opportunities when the collection of environmental data may be applicable to verify the efficacy of implemented control measures, e.g., the collection of air samples for fungal spores after remediation of a fungally-contaminated building. However, the limitations of microbiological sampling methodologies and the paucity of exposure criteria for microbiological agents precludes their use as the sole determinants of the success of the control measures. Success should be objectively determined based on the efficacy of containment (as measured by parameters including removal of dust and debris, pressure differentials, air flow, surrogate indicators of airborne concentrations, and/or other appropriate "tools") and the hazard of the microbiological agent when known.

The control of occupational exposures to chemical, biological, and physical agents is accomplished by the application of engineering measures, work practices, and personal protective equipment (PPE). These measures, practices, and/or equipment are applied at the source of the contaminant generation, to the general workplace environment, or at the significant exposure point of an individual. The application of engineering measures at the source provides the most effective control of both, occupational and environmental contaminants. Source control is amenable to situations where the generation of the etiologic agent is localized. For example, a patient diagnosed with active tuberculosis may undergo aerosolized drug-treatment within the confines of an isolation tent filtered by a high efficiency particulate air (HEPA) filter. Similarly, small local exhaust ventilation units have been suggested for use during the application of lasers and electro-surgical devices (U.S. DHHS, 1996). However, large-scale fungal contamination of the interior surfaces of peripheral walls in an office building are not conducive to

engineering control measures applied at the source of generation. In these situations, the control strategies used are a hybrid of local exhaust and general dilution ventilation.

Substitution with a less hazardous material is the preferred approach to providing a safe work environment. Research activities in microbiology laboratories can be conducted on attenuated or avirulent strains that reduce or eliminate the risk of worker infection. As with many other situations involving microbiological agents, this option may not be available since the agents are usually not an intentional process material. However, the nutrients upon which the organisms feed may be amenable to substitution with substrates that are less conducive to growth. When resolving microbiological contamination of building materials in an indoor environment, materials that contain a high proportion of cellulose may be replaced with other composites. In some instances, work practices can be modified to minimize the potential for contaminant generation and subsequent exposure. Appropriate work practices are a major component of the biosafety program used in microbiology laboratories to reduce the risk of occupational exposures. The application of mechanical pipettors has significantly reduced the possibility of inadvertent infection compared to the technique of employing "mouth pipetting." In 1991, the Occupational Safety and Health Administration (OSHA) published the final rule on occupational exposures to blood borne pathogens based, in large part, on the concept of "universal precautions" (OSHA, 1991). Universal precautions are work practice modifications that treat all human blood and certain other human body fluids as if known to be infected with human immunodeficiency virus (HIV), hepatitis B virus (HBV), and other bloodborne pathogens.

Under those circumstances where source control is not a practical solution, modifications to the general work environment can provide the next level of control. The techniques employed include dilution ventilation, aerosol (e.g., dust) suppression, and improved housekeeping activities. The concept of dilution is one control strategy that has been applied to isolation rooms occupied by patients that have been diagnosed with infectious diseases transmissible through inhalation (e.g., tuberculosis). Riley has suggested that the probability of infection within a ventilated room can be predicted by the application of the Reed-Frost equation (Riley et al., 1989):

$$C = S(1 - e^{-Iqpt/Q}) \qquad \text{[Equation 7-1]}$$

where C is the number of susceptible individuals (S) who become infected, I is the number of sources (actively infected cases), p is the pulmonary ventilation rate (volume per unit time), t is the exposure time in minutes, Q is the removal rate through dilution with fresh air (cubic feet per minute), and q is the quanta (number of doses of airborne infection) added to the air per unit time by an actively infectious case. The risk of infection is reduced by insuring that the airborne concentration is below a known airborne infectious dose.

The last level of control attempts to separate the exposed worker from the chemical, biological, or physical agent. Separation can be attained by the application of isolation environments (e.g., remote control rooms, isolation booths, and supplied-air cabs). In the previous

example of a fungally-contaminated building, large sections of contaminated wall are encapsulated with polyethylene barrier walls that simulate a large biological safety cabinet with contaminated air being exhausted through HEPA filters. The generation source is contained within the structure to protect the environment outside; while the concentrations of airborne fungal spores within the structure are continuously reduced to some equilibrium level based on the calculated volumetric introduction of treated (filtered; possibly dehumidified) outdoor air. Separation can also be achieved by employing PPE including chemically impervious clothing and respirators approved by the National Institute for Occupational Safety and Health (NIOSH). However, PPE should always be considered the "last line of defense" to control occupational exposures.

The selection of an appropriate NIOSH-approved air-purifying respirator is determined by knowledge of the suspected air contaminants (NIOSH, 1996). The size of most bacteria range from 0.3 to 30 micrometers (μm), most disease-causing bacteria range from 0.2 to 1.2 μm in diameter and 0.4 to 14 μm in length; fungal conidia may range from 1 to 50 μm in diameter (Wistreich et al., 1988; Levetin, 1995; Thorne et al., 1999). Viruses and rickettsias are in the sub-micrometer size range, 0.003 to 0.2 μm. Through various mechanisms, these organisms can be disseminated as individual cells, spores, or fragments (or agglomerates there of) or in association with soil/dust, water, or some other particle (as is generally the case with bacteria, viruses, and rickettsias). Particulate respirators certified under Code of Federal Regulations (CFR) Part 84 should offer adequate protection to the wearer against these agents in the majority of instances. Adequate protection is afforded by a proper face seal as determined through a quantitative or qualitative fit test. In selecting an appropriate particulate respirator for use during a specific task, and with known microbiological agents, the NIOSH Respirator Decision Logic Sequence should be applied (NIOSH, 1987). Respirators must be used in accordance with a complete respiratory protection program as specified in OSHA Standard 29, CFR 1910.134 (OSHA, 1992). OSHA requires that respiratory protection programs include written standard operating procedures; respirator selection on the basis of hazard; fit testing; user instruction and training; respirator cleaning, disinfection, storage, and inspection; surveillance of work area conditions; evaluation of the respirator protection program; medical review; and use of certified respirators.

The design of effective exposure controls for microbiological agents depends on an appropriate understanding of the differences between the clinical endpoints (i.e., infection versus immunologic response) and the mechanisms of microbial growth and dissemination. To elicit a response (infectious or immunologic) in a susceptible individual, the microorganism must be present (reservoir), must be capable of propagation to concentrations necessary to induce a response (amplification), and must be dispersed to the susceptible individual (dissemination). Knowledge that the suspected agent is infectious (resulting from a definitive diagnosis of the clinical symptoms) generally carries an awareness of the etiologic agent, including the exposure pathway. For example, engineering the patient environment to reduce the ambient microorganism concentration has been shown to reduce the incidence of nosocomial infections (Sheretz

et al., 1987). The identification of the specific etiologic agent can result in focused control efforts using well-known engineering and administrative control methodologies. However, in many indoor environments, the specific microbiological agents that stimulate the immune response in susceptible individuals to affect a disease state have not been definitively documented. To complicate our understanding of the indoor environment further, the clinical endpoints resulting from exposures to many microbiological agents have not been well-defined. This limited understanding of the etiologic agents and the clinical endpoints results in the application of generalized controls that affect the environment to (presumably) minimize the proliferation of all microorganisms. Generalized control strategies are not as effective as source focused control efforts, such as those applied in the health care industry.

CLINICAL ENDPOINTS (HEALTH EFFECTS)

Infectious Disease

Infectious disease has been defined as an interference with the normal functioning of a host's physio-chemical process resulting from the activities of a microorganism living within the host's tissues or on its surface (Wistreich et al., 1988). Infection specifically refers to the microorganism's presence in the host, the ability to replicate, and the result of the host developing subclinical or clinical disease. It is possible for an individual to be infected with a pathogen and show no (asymptomatic) clinical response. This phenomenon, defined as a carrier state, proves to be the most difficult to control resulting from the inability to definitely identify the source. Infection is characterized by a microorganism's pathogenicity and virulence, the pathogen dose, and the susceptibility or resistance state of the host (Equation 7-2).

$$\text{Infection} \propto \frac{\text{Virulence} \times \text{Dose}}{\text{Host Resistance}} \qquad \text{[Equation 7-2]}$$

In healthcare environments, the risk of infection demands special consideration. Patients or workers with suppressed immune systems (due to certain diseases, targeted immune suppressants, anti-cancer drug, or irradiation treatments) are more susceptible to infection by microbiological agents. This predisposition not only increases the likelihood of infection, but can also result in an increase in the severity of the disease. Additionally, healthcare environments present other distinctive factors that increase the probability of transmission, including a common source of food, water, and air and, unique to specific environments/departments, concentrations of infectious individuals, special environmental infection sources, and the presence of drug resistant microorganism strains (Parker, 1973).

Microorganisms that have been implicated in hospital infections include various viruses, bacteria, and fungi. Based on data from the CDC National Nosocomial Infections Surveillance System (1986-1990), from cultures obtained in 89% of reported nosocomial infections, 85% involved aerobic bacteria; 4% anaerobic bacteria; 9% fungi; and the remaining 2% included a miscellaneous group of viruses, protozoa, and parasites (Martone et al., 1992). Documented

cases of viral nosocomial infections (through direct contact or inhalation of contaminated airborne particles) include varicella-zoster virus, respiratory syncytial virus, adenovirus, HIV, hepatitis B, hepatitis C, and herpes (Gustafson et al., 1982; Chancock et al., 1961; Brummitt et al., 1988; Snydman et al., 1976; Perl et al., 1992). Certain bacterial species, predominantly Gram-negative organisms including *Escherichia coli*, *Enterobacter* spp., *Pseudomonas* spp., and *Proteus* spp., have been associated with bacteremia and death in hospital environments. Gram-negative bacteria are primarily transmitted through contact, with contaminated fluids, moist objects, or ingestion. Many gram-positive bacteria also pose significant nosocomial concerns. *Staphylococcus aureus* is reportedly responsible for approximately 10% of all nosocomial infections (CDC, 1982). Recently, tuberculosis has received increased attention as an important nosocomial disease due to the emergence of multidrug-resistant strains, and the report of several outbreaks in healthcare settings (CDC, 1990).

Fungal agents pose unique nosocomial concerns. Their ubiquitous and hardy existence have weakened the ability to recognize, and subsequently control, indoor exposures. *Aspergillus* spp. are the primary environmental fungal nosocomial hazards; they are opportunistic pathogens in individuals with suppressed immune systems. Lentino et al. reported 10 cases of acquired aspergillosis among immunosuppressed patients resulting from treatment of hematologic malignancy, advanced age, or drugs taken to prevent rejection of renal allografts (Lentino et al., 1982). It was suggested that road construction activities adjacent to the hospital may have disturbed spore-containing soil that could not be appropriately filtered by window air-conditioning units. *Aspergillus* spp. were recovered from the selected air-conditioning units.

Immunologic Response

Immunologic responses are activated by an individual's reaction to particular antigenic constituents of a given microbial species. These responses and the subsequent expression of allergic disease are based on the type and extent of the exposures and, in part, on a genetic predisposition (Pickering, 1992). Allergic respiratory diseases [including allergic rhinitis, allergic asthma, allergic bronchopulmonary aspergillosis (ABPA), and hypersensitivity pneumonitis (HP) resulting from exposures to microbiological agents have been documented in agricultural, biotechnology, office, machining, and home environments (Vinken et al., 1984; Malmberg et al., 1985; Topping et al., 1985; Edwards, 1980; Weiss et al., 1971; Hodgson et al., 1985; Fink et al., 1971; Banazak et al., 1974; Campbell et al., 1979).

Symptoms vary with the type of allergic disease: (1) Allergic rhinitis is characterized by paroxysms of sneezing; itching of the nose, eyes, palate, or pharynx; nasal stuffiness with partial or total airflow obstruction; and rhinorrhea with postnasal drainage. (2) Allergic asthma is characterized by episodic or prolonged wheezing and shortness of breath due to bronchial narrowing and mucus hypersecretion. (3) ABPA is characterized by symptoms of cough, lassitude, low grade fever, wheezing, and occasional expectoration of mucous (Burge, 1988; Kaliner et al., 1987). Exposures to large concentrations of airborne microorganisms may result in an acute form of hypersensitivity pneumonitis (HP, also known as extrinsic allergic alveolitis), which is

characterized by chills, fever, malaise, cough, and dyspnea (shortness of breath) generally appearing four to eight hours after exposure. Chronic HP is thought to be induced by a continuous low-level exposure, and onset occurs without chills, fever, or malaise but is characterized by progressive shortness of breath with weight loss (Jordan, et al., 1987). Chronic HP of sufficient duration results in progressive loss of lung function. The disease is not reversible and patients must be removed from exposure. This can be accomplished either by removing the patient from the presence of the sensitizing agent, or removing the sensitizing agent from the patient, to halt progression of the disease.

Acceptable levels of airborne microorganisms have not been established for a) total culturable or countable bioaerosols; b) specific culturable or countable bioaerosols other than infectious agents; c) infectious agents; or d) assayable biological contaminants for the reasons identified below (ACGIH®, 2000). Total culturable or countable bioaerosols exist as a complex mixture of different microbial, plant, and animal particles that produce widely varying human responses, depending on the susceptibilities of the individual. This fact, and the lack of a single sampling method that can adequately characterize all bioaerosol components, limits the ability to produce sufficient information to describe the exposure-response relationships that can predict human health effects. The scientific data that are available consist of case reports and qualitative exposure assessments, which are generally insufficient as well. The absence of good epidemiologic data on exposure-response relationships related to specific culturable or countable bioaerosols has resulted from the derivation of data from indicator measurements as opposed to actual effector agents. Also, the variations of bioaerosol components and concentrations among differing occupational and environmental settings, combined with the limitations of sampling methodologies, have resulted in the inaccurate representation of workplace exposures. Human dose-response relationships are available for some infectious bioaerosols. However, facilities associated with increased risks for airborne disease transmission rely on the application of engineering and administrative controls to minimize the potential for workplace exposure. In the future, some assayable, biologically derived contaminants (e.g., endotoxin) may lend themselves to the development of numeric criteria due to advances in assay methods.

Relationships between health effects and environmental microorganisms must be determined through combined medical, epidemiologic, and environmental evaluations. The current strategy used by NIOSH for on-site evaluation of indoor environments where microorganisms are the suspected etiologic agent involves a comprehensive inspection of the building to identify sources of microbial contamination and routes of dissemination. In those locations where contamination is visibly evident or suspected, bulk samples may be collected to identify the predominant species (fungi, bacteria, and thermoactinomycetes). In limited situations, additional environmental samples (e.g., air samples) for microorganisms may be collected to test a specific hypothesis, such as to document the presence and dissemination of a suspected microbial contaminant or to determine if microorganisms from reservoirs or amplifiers are entering indoor air. Elevated airborne concentrations of the contaminant in the high-symptom area,

compared to outdoor and low-symptom areas, and anomalous ranking among the microbial taxa may suggest that the contaminant is responsible for the health effects.

Disease Incidence

For certain diseases that carry a high incidence, such as acute viral gastroenteritis from Norwalk-like viruses or influenza (influenza virus), cases may arise from both community outbreaks and occupational exposures. Three of the most prevalent life-threatening infectious diseases associated with occupational exposures in the U.S. are tuberculosis, viral hepatitis from hepatitis B virus, and Lyme disease. Of course, these diseases also occur outside of the workplace. Some infectious diseases with an occupational association have exhibited a steady incidence over the past two decades (e.g., Legionellosis). Others occur episodically depending upon environmental conditions (e.g., Hantavirus pulmonary syndrome), epizootic outbreaks (epidemics among animals), or human error (e.g., foodborne illnesses).

There is little data available from which to determine incidence or prevalence for most occupational infectious diseases. In the United States, cases of federally notifiable diseases must be reported to the CDC. Table 7-1 lists data for 1997 from the CDC for those infectious diseases that pose a significant occupational risk. These cases are reported from the entire U.S. population (a denominator of 267 million), but are important risks for the civilian workforce of 138 million. The degree to which each of these case numbers represents occupational exposure varies by disease and is largely unknown. For several specific diseases and job titles, there are incidence data that were collected to demonstrate the efficacy of preventive measures. For instance, for hepatitis B in health care workers, there were about 8,700 cases per year (145 cases per 100,000) in the United States prior to widespread vaccination and implementation of educational and administrative programs. The CDC has documented that by 1994, this figure had declined to under 1,000 annual cases (16 cases per 100,000).

Prevention

There are many approaches to the prevention of occupational infections and these have been implemented with varying degrees of success. Preventive measures tend to have the greatest efficacy in settings where workers are concentrated, where the workforce is well structured, where the hazards are recognized, and where there are sufficient resources to provide physical controls, training programs, and surveillance. To a large extent the health care system meets these conditions. In hospitals, health clinics, and dental clinics, implementation and enforcement of universal precautions, vaccinations, use of disposable products, proper waste handling procedures, and detailed administrative controls have increased the safety of the workplace. Still there are an estimated 600,000 needle stick injuries annually among health care workers in the United States. One-third of these occur during disposal of the syringe or sharp object. The risk of infection after a needle stick is 0.3% for HIV, 6 to 30% for hepatitis B virus, and 5 to 10% for hepatitis C virus. In contrast to health care settings, many occupations have little structure

Table 7-1
Reported cases in the United States (1997 data) for infectious diseases with a significant occupational component. Data specific for occupational cases are not available.‡

Disease	Reported U.S. Cases
Arboviral encephalitides	47
Brucellosis	98
Cryptosporidiosis	2,566
Hepatitis B	10,416
Legionellosis	1,163
Lyme disease	12,801
Plague	4
Psittacosis	33
Rabies	2
Rocky Mountain spotted fever	409
Tetanus	50
Tuberculosis	19,851

‡The denominator for calculating population-wide incidence was 267,637,000.

and workers are disseminated, making preventive measures difficult to develop and implement. Examples include workers in agriculture, fishing, forestry, composting and waste handling, and animal handlers.

Table 7-2 lists six components necessary for an effective infection control program. Control strategies generally encompass engineering controls such as high performance ventilation systems, biosafety cabinets, special equipment (e.g., retracting needles), specially-designed waste containers, and apparatus to isolate the worker from the hazard. Personal measures such as

Table 7-2
Components of effective workplace infection control programs

• Identify occupational infection risks and develop control measures
• Educate workers about infection control and personal responsibility
• Coordinate infection control personnel to effectively monitor cases and control outbreaks
• Institute a program of immunization for agents that have an approved vaccine
• Institute an administrative structure to monitor compliance and efficacy and ensure confidentiality
• Provide health care and counseling for workers who sustain exposures to develop occupational infectious diseases

hand washing, immunization, and use of personal protective equipment (gloves, safety glasses, respirators, etc.) are also important. Administrative controls include worker screening, criteria for returning to work following illness or exposure, emergency response for prevention of exposures or outbreaks, controlled access to hazardous areas, and biosafety enforcement. An effective system for surveillance should also be implemented. For diseases transmitted from pets, livestock, and zoo animals, immunization of the animals can help protect those who handle them.

Where infectious diseases are transmitted by an arthropod vector, protective clothing, insect and tick repellants containing n,n-diethyl meta-toluamide (DEET) or pyrethrins, and careful inspection for ticks are important for disease risk reduction. Avoiding work at dawn or dusk can significantly reduce mosquito bites. Chemoprophylactic therapies and vaccinations are important for soldiers, travelers, and those who work outside. However, some of these drugs are not recommended for immunocompromised workers, pregnant workers, or individuals with certain enzyme deficiencies. It has been shown that taking chloroquine as a prophylactic treatment for malaria can interfere with the development of protective antibodies following vaccination against rabies. There are also concerns regarding heavy use of dermally-applied insecticides concurrent with chemoprophylactic therapies and vaccinations.

Community or worksite-based vector control programs can be helpful. For mosquito control, draining swamps, disposing of discarded tires, covering water reservoirs, and use of insecticides are helpful for primary prevention. Many countries have instituted surveillance programs using sentinel animals for tracking mosquito borne diseases. As an example, the United States monitors small groups of captive chickens disseminated throughout regions where Arboviruses appear. A high correlation between seroconversion of the chickens for the agents that cause Western equine encephalitis and disease in horses and humans in those same regions has been observed. Rodent control through elimination of food sources; rat-proofing of buildings;

eradication programs using traps, fumigants, and poisons; habitat elimination; and proper rubbish containment and collection are highly effective control measures. Another important avenue toward lowering rodent populations is reducing poverty and improving the social structure within a community.

Occupational infectious diseases cause significant morbidity and mortality and result in personal suffering and lost productivity. While they can affect any worker, certain occupations carry greater risks. Recognition of the hazards and implementation of appropriate preventive measures can reduce the incidence and severity of these occupational diseases.

MICROBIAL AGENTS IN HEALTH CARE FACILITIES

The occupational hazards encountered by health care professionals are varied. These hazards include exposures to biological, chemical, and physical agents, as well as ergonomic challenges posed by the manipulation and transport of patients. In a 1988 document (NIOSH, 1988) that focused on protecting the safety and health of health care workers, NIOSH determined that, compared to the civilian workforce, hospital workers have a greater percentage of workers' compensation claims for sprains and strains, infectious (e.g., hepatitis) and parasitic diseases, dermatitis, mental disorders, eye diseases, influenza, and toxic hepatitis. Probably, the most occupationally unique and high risk hazards are those posed by exposure to infectious agents. In some instances, the risk of occupationally acquired infections is of such concern that comprehensive, agent focused guidelines have been published by the CDC. Specifically, these guidelines have addressed occupational exposures to *Mycobacterium tuberculosis*, HIV, and HBV (CDC, 1994; CDC, 1989). In 1991, OSHA published their final rule on occupational exposures to blood borne pathogens (OSHA, 1991). Additionally, in 1997, OSHA published a draft standard for enforcement procedures for occupational exposures to tuberculosis (OSHA, 1996).

The effective management and control of bioaerosols in hospital environments requires a comprehensive understanding of the possible antigenic or infectious nature of microorganisms, the susceptibility of the host, and the ability of the investigator to predict dissemination pathways based on the available information. Designing the patient environment to reduce the ambient microorganism concentration has been shown to reduce the incidence of nosocomial *Aspergillus* infections (Sheretz et al., 1987). Invasive medical procedures significantly enhance the ability of an organism to invade and colonize a host. Based on current estimates, surgical wound infections account for one-fourth of all nosocomial infections. Studies conducted by the CDC have estimated the national rate of nosocomial infections (among all patients admitted to hospitals for reasons other than infections) to be approximately 5% (Eickhoff et al., 1969; Haley et al., 1985).

The diversity of health effects (immunogenic or infectious) of microbiological agents in the hospital environment dictates a multi-disciplinary control approach that includes infection control personnel, biosafety officers, and industrial hygienists. Infection control personnel

focus primarily on nosocomially acquired infections through the activities of an infection control program. An organized program should include (Fleming, 1989):

- Collection and analysis of infection control data (surveillance)
- Planning, implementation, and evaluation of infection prevention and control measures
- Education of individuals about infection risk, prevention, and control
- Development and revision of infection control policies and procedures
- Investigation of suspected outbreaks of infection
- Provision of consultation on infection risk assessment, prevention, and control strategies

Issues related to chemical or biological hazards other than nosocomial control are coordinated through the biosafety officer and/or industrial hygienist. Responsibilities of the various disciplines may overlap in certain situations. A typical example includes the recognition, evaluation, and control of microbiological contamination in a hospital ventilation system. In this example, an epidemiologic assessment may indicate a cluster of aspergillosis among patients. Environmental investigation confirms the presence, amplification, and dissemination of microbiological reservoirs. Subsequent interaction with the engineering staff can then foster solutions that (1) protect the workers and patients during remediation activities and (2) prevent the recurrence of similar events.

Infectious diseases contracted through the airborne route are the most amenable to the industrial hygiene precepts of recognition, evaluation, and control. The rapid clinical diagnosis of a disease in an individual results in the *recognition* of not only the etiologic agent, but may suggest the identification of the source as well. Knowledge of the etiologic agent generally means information on the route of transmission. Infectious diseases can be contracted through five primary pathways (i.e., oral, contact, penetration, respiratory, and via vectors such as insect bite). The first four pathways are generally the predominant focus in health care settings.

Airborne Pathogens

The strategies used to control occupational infectious disease exposures transmitted through the airborne pathway are best exemplified by the 1994 CDC tuberculosis guidelines. The increasing worldwide incidence of tuberculosis has resulted in a global recognition of the resurgence of this disease (see Figure 7-1) (WHO, 1996). The 1994 CDC tuberculosis guidelines were designed to address the prevention of tuberculosis transmission in health care facilities using a hierarchical control structure including administrative, engineering, and PPE control measures. Clearly, the early identification, isolation, and treatment of individuals having active tuberculosis is the basis of an effective control program. These concepts are addressed in the development of the administrative control measures. However, engineering control measures can be effective supplements during the time between case identification and disease resolution

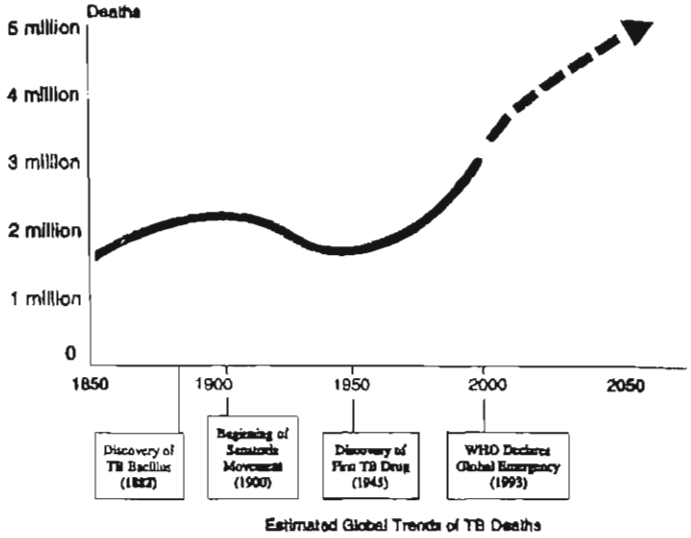

Figure 7-1. Global trends of tuberculosis deaths (adapted from WHO, 1996).

subsequent to treatment. Engineering controls can establish an environment that confines the airborne infectious particles in an isolated area. The engineering control measures employed include general and local exhaust ventilation, the application of ultraviolet germicidal irradiation (UVGI) or HEPA filtration or both, and respiratory protection.

Local exhaust ventilation (LEV) is applicable to those situations where control at the source can significantly reduce the concentration of the generated aerosol. Procedures that are amenable to LEV include sputum induction, bronchoscopy, intubation, irrigation, and aerosolized drug therapy. These activities induce the patient to cough (or otherwise release aerosols) that potentially contain significant concentrations of tubercle bacilli. For example, sputum induction can be conducted inside a booth designed to filter the air surrounding the patient before exhausting it back into the room (see Figure 7-2). Enclosures (i.e., booths and tents) create an encapsulated (enclosed) environment around the patient. The containment barrier is defined by the enclosure structure and by negative pressure (with respect to the atmosphere outside of the enclosure) induced by exhausting air. The air can be exhausted directly to the outdoors or recirculated into the room. However, it is critical that the exhausted airstream (especially for recirculated air) be appropriately filtered to ensure removal of airborne tubercle bacilli (typically in the size range between 1 to 5 μm). Air exhausted outdoors should be filtered if there is a possibility of contaminated air to re-enter the building or if it is exhausted into an outdoor area that could potentially expose other individuals. For infectious agents that pose a significant airborne risk (e.g., *Mycobacterium tuberculosis*), filtration should be accomplished

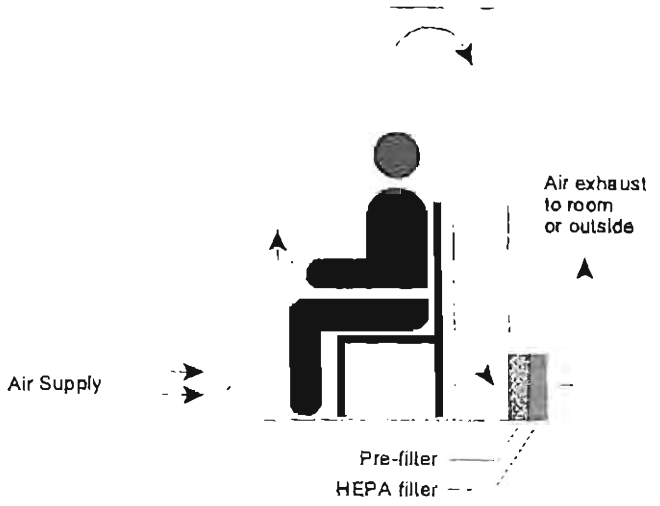

Figure 7-2. Isolation booth for sputum induction.

with HEPA filters which are 99.97% effective in removing particles greater than or equal to 0.3 μm in diameter.

General ventilation introduces a clean airstream into the space occupied by the infectious individual to dilute the contaminant concentration to a level that reduces the risk of exposure to airborne tubercle bacilli. The introduced air may originate from a conditioned outdoor source or from a highly filtered, recirculated source. Effective dilution assumes a homogeneous mixture in the occupied space, i.e., the provision of airflow patterns that promote the mixing of the air and contaminants. Contaminant dilution is a function of the exhausted volumetric air flow, the volume of the room, and time. Disseminated tubercle bacilli have been assumed to move in air similar to gases. (Note, the tracer gas, sulfur hexafluoride, has been suggested to be an acceptable surrogate to track the movement of *M. tuberculosis* in air (Decker, 1995).) This assumption allows the estimation of the removal efficiencies over varying values of air changes per hour (ACH). The time (units of minutes) to achieve varying removal efficiencies as a function of ventilation rate (ACH computed from the exhaust flow rate divided by the room volume) may be determined by the following purge equation:

$$\Delta t = \left(-\frac{1}{ACH} \ln \left(\frac{C_2}{C_1} \right) \right) \times 60 \qquad \text{[Equation 7-3]}$$

where C_1 is the initial concentration and C_2 is the concentration after a known time interval (Δt). Table 7-3 provides calculations of the minutes required for varying removal efficiencies (de-

Table 7-3
ACH required for removal efficiencies [100(1-C_2/C_1)] of airborne contaminants

ACH	Minutes		
	90%	99%	99.9%
1	138	276	414
2	69	138	207
3	46	92	138
4	35	69	104
5	28	55	83
6	23	46	69
7	20	39	59
8	17	35	52
9	15	31	46
10	14	28	41
11	13	25	38
12	12	23	35
13	11	21	32
14	10	20	30
15	9	18	28
16	9	17	26
17	8	16	24
18	8	15	23
19	7	15	22
20	7	14	21
25	6	11	17
30	5	9	14
35	4	8	12
40	3	7	10
45	3	6	9
50	3	6	8

Source: Adapted from CDC, 1994

fined as $(1 - C_2/C_1) \times 100$ and ACH computed from Equation 7-3. CDC has recommended a volumetric air change rate in tuberculosis isolation rooms of 12 ACH for new construction and 6 ACH for renovated rooms. These values were selected based on studies that indicated that rates greater than 6 ACH were likely to produce incrementally greater reduction of bacterial concentrations compared with lower ventilation rates.

Air should be introduced and, subsequently exhausted, in a manner that moves the uncontaminated airstream from the health care worker's breathing zone through the patient's breathing zone (see Figure 7-3). Therefore, supply/exhaust diffuser placement becomes critical to the mixing and general movement of the air in the room. Poor mixing may result in short-circuiting (between supply and exhaust diffusers) and/or stagnation zones that do not allow contaminants to be efficiently removed. The values calculated in Table 7-3 assume perfect mixing of the air within the space (i.e., mixing factor = 1). However, perfect mixing does not occur; for very poor air distribution the mixing factor can range to 10, increasing the values in Table 7-3 accordingly.

Isolation rooms, by definition, are designed to contain generated contaminants within the confines of the room. This containment is achieved by the physical barriers created by the room structures (i.e., walls, ceilings, doors, and windows) and by the creation of negative pressure differentials with respect to adjacent areas. By exhausting air at a volumetric flow rate that is greater than what is supplied to the room, negative pressure differentials are created. These differentials are designed to create a directional flow of air from clean to contaminated areas. Balancing the ventilation system so that the exhaust flow rate is 10% or 50 cubic feet per minute (cfm, 1416 liters per minute [lpm]) greater than the supply air flow rate should achieve a pres-

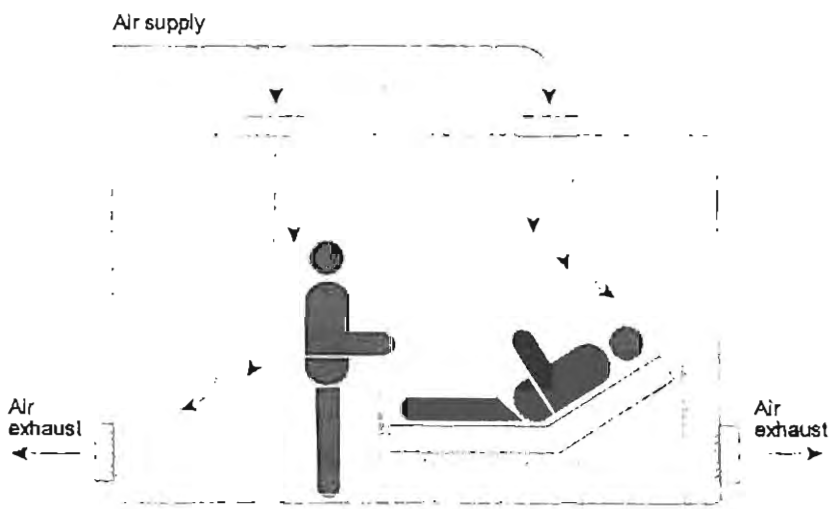

Figure 7-3. General ventilation for isolation rooms.

sure differential of at least 0.001 inches water gauge (0.25 Pa). The aggregate flow restrictions resulting from leakage areas within the enveloping structure of the room determine the attainable pressure differential. If the minimum pressure level cannot be achieved within the limitations of the ventilation system, the degree of room leakage should be assessed and subsequently corrected. Negative pressure isolation rooms are designed to properly operate with the entry/exit door closed. Doors that remain open will significantly impact the ability of the ventilation system to maintain the proper pressure differential. However, it has been experimentally demonstrated that the opening and closing of the entry/exit door and the movement of personnel into and out of the isolation room have little effect on the migration of air into or out of the room (Hayden et al., 1998).

Preventive maintenance is critical to the performance of the containment systems within isolation rooms. Verification of the room pressure status should be conducted on a routine basis (daily at a minimum) to ensure that containment is maintained. Pressure status can be monitored qualitatively or quantitatively. Qualitative assessment is conducted by observing the direction of chemically generated smoke at leakage points around the entry/exit door. The movement of smoke into the isolation room from the adjacent hall or room indicates negative pressure. Quantitative information can be attained with the aid of differential pressure-sensing devices. These devices can be used periodically (monitoring by an individual moving from room to room) or continuously (pressure sensors permanently installed across the hall/isolation room connecting wall).

Administrative measures are the basis of an effective infectious disease control program and engineering measures provide supplemental control. However, general ventilation does little to reduce the exposure encountered at close range to the active tuberculosis patient. Exposures at close range can result from inhaling a concentrated aerosol bolus released by the patient during coughing and sneezing. In those situations when administrative and/or engineering controls are not capable of adequately reducing the potential for occupational exposures to airborne infectious agents, respirators should be used. The selection of the appropriate respirator is based on the expected size range of the microbiological agent and the hazard associated with that agent. The CDC recommends that the minimum respirator for encounters (i.e., in isolation rooms, during vehicle transport, or during cough-inducing procedures) with individuals who have or are suspected of having tuberculosis should meet the following criteria:

- ability to filter particles 1 μm in size in the unloaded state with a filter efficiency of greater than or equal to 95%
- the ability to be qualitatively or quantitatively fit tested in a reliable way to obtain a face–seal leakage of less than or equal to 10%
- the ability to fit the different facial sizes and characteristics of wearers
- the ability to be checked for facepiece fit upon donning, in accordance with OSHA standards and good industrial hygiene practice

Although the filter media used in many current surgical masks may meet the first criterion, they may not meet the latter three. The flat designs often seen in these masks (with elastic straps that secure the mask around the head or ears) cannot provide the quality seal of molded (including "duck bill" designs) respirators. In experimental studies challenging surgical masks with artificially generated aerosols of *Bacillus subtilis* subsp *niger*, inadequate face seal accounted for approximately 85% of the penetration (Johnson et al., 1994). Additionally, these masks are not easily amenable to donning checks for facepiece fit. As a result, surgical masks worn by health care workers are not appropriate respiratory protection against airborne *Mycobacterium tuberculosis* or other infectious microbiological agents. A study of the filter efficiency of respirators and surgical masks challenged with mycobacterial aerosols showed a geometric mean penetration rate of 22 percent for non-approved (i.e., devices that have not been certified under 30 CFR Part 11) surgical masks (Brosseau et al., 1997). Another study demonstrated that aerosol penetration for sub-micrometer size particles may range from 5 to 100 percent for the eight evaluated surgical masks (Weber et al., 1993). Such masks are designed to reduce the potential for contamination of the patient operating field by capturing large bacterial laden aerosols emitted from the mouth and nose of the medical staff. However, these masks can be worn by tuberculosis infected patients to minimize their expulsion of tubercle bacilli.

NIOSH-approved respirators with an N95 designation (as defined by the current NIOSH certification procedures 42 CFR 84 effective July 10, 1998) would meet or exceed the CDC standard performance criteria. The filter material of the N95 particulate respirator has been certified to be at least 95% efficient at removing particles at the most penetrating size (approximately 0.3 μm). The CDC guidelines state that a facility's risk assessment may identify settings where the estimated risk for transmission of *Mycobacterium tuberculosis* may be at such a high level that the standard selection criteria may not be stringent enough. Careful risk assessment techniques should be employed to determine if a higher level of protection is required.

Bloodborne Pathogens

The hazards posed by occupational exposures to infectious agents in blood and bodily fluids have become globally recognized issues. On a historical time-scale, this increased awareness is a recent event. Since the beginning of the 1920s, published reports of laboratory-associated infections have grown steadily, with an increasing percentage caused by exposures to hepatitis (Pike, 1979). The CDC has estimated that, in 1987, the total number of HBV infections in the United States was 300,000 per year, with approximately 25% of those infected developing acute hepatitis. Additionally, the CDC has estimated that 12,000 health care workers (whose job duties put them at risk for exposures to blood) will become infected with HBV each year resulting in the yearly hospitalization of 500-600 workers and approximately 250 deaths (CDC, 1989). However, as a result of vaccine use and adherence to other preventive measures, there has been a 90% reduction in the number of HBV-infected health care personnel from 1985 to 1994 (Shapiro, 1995). Within the health care industry, certain situations (i.e., autopsies) are known to present the greatest risk of exposure to both bloodborne pathogens and other infec-

tious agents. During autopsies, the increased risk to the pathologist and pathology technicians may be due to the presence of unknown etiologic agents in the decedent and exposure to large amounts of infectious material resulting in the release of these agents during invasive procedures. The infectious diseases of particular concern during autopsies have included tuberculosis, hepatitis B (HBV) and C virus, HIV, Creutzfeldt-Jacob disease, group A streptococcal infection, gastrointestinal infections, and possibly meningitis and septicaemia (especially meningococcal) (Healing et al., 1995; Young and Healing, 1995).

In 1991, OSHA published a final rule on occupational exposures to bloodborne pathogens (OSHA, 1991). The bloodborne pathogens rule is in part based on the concept of "universal precautions." Universal precautions are defined as the treatment of all human blood and certain other human body fluids as if known to be infected with HIV, HBV, and other bloodborne pathogens. Under the OSHA regulation, blood is defined as human blood, human blood components, and products made from human blood. Bloodborne pathogens include any pathogenic agents that are present in human blood and that can cause disease in humans. The definition of other potentially infectious materials are inclusive of human body fluids; any unfixed tissue or organ from a human; HIV-containing cell or tissue cultures, organ cultures, and HIV- or HBV-containing culture medium or other solutions; and blood, organs, or other tissues from experimental animals infected with HIV and HBV.

If employees are potentially (i.e., "reasonably" anticipated) exposed to human blood or bodily fluids in the performance of their normal duties, then an exposure control plan should be developed. Components of the plan should include exposure determinations, schedules and methods of implementing compliance methods, HBV vaccination and post-exposure evaluation and follow-up, hazard communication to employees, recordkeeping, and written procedures for circumstances surrounding exposure incidents. The determination of exposure must list all job classifications in which all employees have occupational exposures, all job classifications in which some employees have occupational exposures, and all tasks and procedures or groups of closely related tasks and procedures in which occupational exposure occurs.

Exposure control methods should always be based on the precept of "universal precautions." There are three primary categories of control: engineering and work practice controls, personal protective equipment, and housekeeping. Engineering controls include the provision of hand-washing facilities; appropriate containers for needles and sharps disposal and for specimens of blood or potentially infectious materials; and the use of laboratory equipment that minimizes splashing, spraying, spattering, generation of aerosol droplets (this can also be achieved through work practices), and potential direct contact exposures (e.g., the use of mechanical pipetting devices instead of mouth pipetting). Work practice controls rely on the vigilant awareness and continuous cooperation of the worker to identify potential exposure situations and subsequently apply established protective practices. These practices should include hand washing after removal of PPE or following contact with blood or potentially infectious materials; the prohibition of eating, drinking, and smoking, except in designated areas; and the exclusion of food and drink from storage areas reserved for blood and potentially infectious materials. Ad-

ditional work practice controls can be developed to fit each unique exposure situation as long as "universal precautions" are maintained.

Various levels of PPE may be employed depending on the "reasonably" anticipated exposure risk. The equipment includes gloves, gowns, laboratory coats, face shields or masks and eye protection, and mouthpieces, resuscitation bags, pocket masks, or other ventilation devices. Masks, eye protection, and face shields should be worn whenever splashes, spray, splatter, or aerosol droplets of blood or other potentially infectious materials are generated or anticipated. It is the employer's responsibility to make these items accessible to employees; ensure their use; clean, launder, or dispose of used items; and repair or replace them as necessary. If a garment has been penetrated by blood or other potentially infectious materials, the item should be removed immediately (or as soon as feasible). All PPE should be removed and placed in an appropriate container prior to leaving the immediate work area. Disposable (single-use) gloves may be used but should be replaced as soon as possible when contaminated or if their barrier properties are compromised. These damaged items should *never* be reused. Utility gloves can be decontaminated for reuse if the integrity of the glove is not compromised.

The last control strategy involves housekeeping practices that maintain the work site in a clean and sanitary condition. All equipment and working surfaces should be cleaned and decontaminated immediately after contact with blood or other potentially infectious material. Additionally, work surfaces should be decontaminated upon completion of procedures, immediately after overt contamination or spill of blood or other potentially infectious materials, and at the end of the work shift if contamination occurred since the last cleaning. Work surface protective coverings should be removed after overt contamination or at the end of the work shift. Receptacles intended for reuse that have a reasonable likelihood of becoming contaminated should be visually inspected and decontaminated on a regularly scheduled basis, and immediately if visibly contaminated by blood or potentially infectious materials. Broken glassware should be extracted by mechanical devices, not with the hands if suspected of contamination. All contaminated sharps and other regulated waste should be placed in appropriately designated containers. Laundry that is contaminated with blood or other potentially infectious materials should be handled as little as possible, with an effort to minimize agitation, and should be placed in appropriate bags or containers.

Monitoring Environmental Contaminants in the Healthcare Setting

In specific instances, environmental microbiological sampling can serve as an essential adjunct to the infection control program. Using various environmental sampling methods (i.e., bulk, surface, and air), Lentino et al. established a correlation between aspergillosis case clusters among renal transplant patients, adjacent road construction, and the recovery of *Aspergillus fumigatus* and *A. flavus* from window air conditioners. Sawyer et al. collected air samples of varicella-zoster virus (VZV) to document the dissemination of viral particles outside of negative-pressure isolation rooms occupied by VZV patients (Sawyer et al., 1994). However, the *evaluation* of the health care environment (characterized by the collection of exposure data) is

not routinely conducted. There is no evidence that routine environmental microbiological sampling is necessary for the maintenance of good practices in hospital environments, nor has it been shown that routine sampling has significantly influenced the incidence of nosocomial infections. In 1970, the CDC and the American Hospital Association (AHA) changed their original recommendations for microbiological sampling of the environment to advocating the discontinuation of most routine environmental sampling in hospitals (CDC, 1970; AHA, 1974). Environmental sampling has only been indicated for (1) documenting the effectiveness of various sterilization processes, (2) monitoring infant formulas prepared in the hospital, (3) checking for high levels of contamination on certain patient-care supplies, and (4) as a supplemental tool used in the investigation of an infection outbreak or other specific problem (Mallison and Haley, 1981).

MICROBIOLOGY LABORATORIES AND BIOSAFETY LEVEL

Laboratories engaged in microbiological research and/or analytical support services present unique occupational exposure risks (see Figure 7-4). The variety, pathogenicity, and concentrations of the microbial agents can be significantly greater than in other occupational settings. For example, *Mycobacterium tuberculosis* (Mtb) has been identified in recent years as posing a significant risk to laboratory personnel. Studies have shown that the incidence of Mtb infection in those who work with Mtb in the laboratory is 3 to 5 times higher than the incidence among laboratory personnel who do not work with the bacterium (Reid, 1957; Capewell et al., 1988; Harrington and Shannon, 1976).

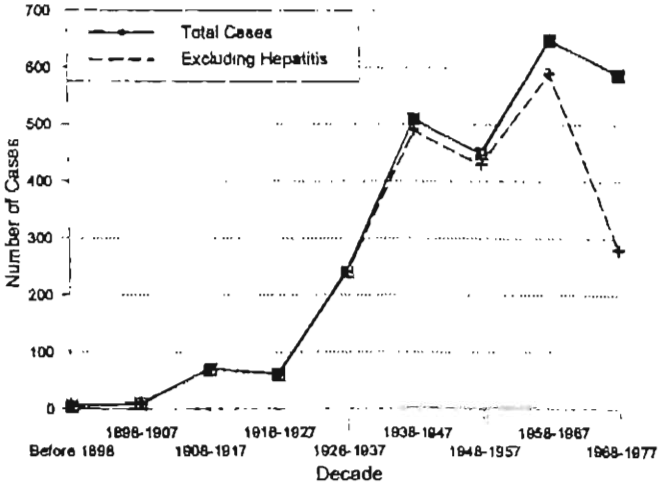

Figure 7-4. Cases of laboratory associated infections (adapted from Pike, 1979).

One of the more common routes of infection of laboratory-acquired illnesses has been attributed to the inhalation of aerosols (Sewell, 1995). Some aerosol-generating procedures that have been shown to produce droplet nuclei in the respirable size range include: pouring of cultures and supernatant fluids, using fixed volume automatic pipettors, mixing a fluid culture with a pipette, dropping tubes or flasks of cultures, spilling suspensions from pipettes, and breaking tubes during centrifugation (Kenney and Sabel, 1968; Stem et al., 1974; McKinney et al., 1991). Additional concerns for microbiologists processing clinical samples include: (1) the increasing numbers of multiple drug resistant organisms, and (2) the increasing numbers of individuals who are co–infected with HIV.

In 1974, the CDC published the first in a series of booklets outlining categorization levels for facilities and practices to be used for activities with infectious agents (CDC, 1974). These guidelines have evolved into the CDC/National Institutes of Health publication, *Biosafety in Microbiological and Biomedical Laboratories* (CDC/NIH, 1993). This booklet discusses the concepts of primary and secondary containment and their application to four levels of biosafety for microbial agents based on hazard and the specific function or activity of the laboratory. Combinations of microbiological practices, laboratory facilities, and safety equipment (including biological safety cabinets [BSC]) are described within each of the four categories (see Table 7-4). Within each biosafety level, the management of infectious agents is facilitated by the precepts of isolation and containment. As with the control of exposures to chemical agents, containment should be designed to protect the laboratory workers, other individuals not involved with laboratory activities, and the outside environment. The concept of containment can be further sub-divided into primary and secondary levels. Primary containment should protect laboratory personnel and the immediate working environment through the application of appropriate work practices and safety equipment. Secondary containment ensures that infectious agents do not contaminate the environment external to the laboratory via the implementation of appropriate facility design and operational procedures.

Biosafety Level (BSL) 1 provides the least protective environment for microbiological activities as it does not include specifications for primary or secondary containment barriers (defined below). BSL 1 laboratories are encountered in such settings as academia, where the work is with microbial agents not known to cause disease in healthy humans. Subsequent increases in the hazard of the microbial agents will result in the need for more protective biosafety levels. BSL 4 facilities are intended for activities with dangerous and exotic microbial agents that pose significant risk of aerosol-transmitted and life-threatening infectious disease. Examples of microorganisms that are included in BSL 4 are the Marburg, Ebola, Lassa, and Machupo viruses. These facilities include provisions for limited access, specialized training for the handling of high-risk microbial agents, facility isolation through the use of physical barriers and negative pressure relationships with adjacent areas, and all activities confined to Class III biological safety cabinets (BSC – defined below) or Class II BSCs in conjunction with personnel equipped with one-piece positive pressure suits ventilated by a life support system. Varying combinations of work practices, facility design, and safety equipment are encountered with BSL 3 and BSL 4 (see Table 7-4).

Table 7-4
Summary of recommended biosafety levels for infectious agents

Biosafety Level	Agents	Practices	Safety Equipment (Primary Barriers)	Facilities (Secondary Barriers)
1	Not known to cause disease in healthy adults.	Standard Microbiological Practices.	None required.	Open bench top sink required.
2	Associated with human disease, exposure via autoinoculation, ingestion, mucous membrane exposure.	BSL-1 practice plus: Limited access; Biohazard warning signs; "Sharps" precautions; Biosafety manual defining any needed waste decontamination or medical surveillance policies.	Primary barriers = Class I or II BSCs or other physical containment devices used for all manipulations of agents that cause splashes or aerosols of infectious materials; PPE; laboratory coats; gloves; face protection as needed.	BSL-1 plus: Autoclave available.
3	Indigenous or exotic agents with potential for aerosol transmission; disease may have serious or lethal consequences.	BSL-2 practice plus: Controlled access; Decontamination of all waste; Decontamination of lab clothing before laundering; Baseline serum.	Primary barriers - Class I or II BSCs or other physical containment devices used for all manipulations of agents; PPE; protective lab clothing; gloves; respiratory protection as needed.	BSL-2 plus: Physical separation from access corridors; Self-closing, double-door access; Exhausted air not recirculated; Negative airflow into laboratory.
4	Dangerous/exotic agents which pose high risk of life-threatening disease, aerosol-transmitted lab infections; or related agents with unknown risk of transmission.	BSL-3 practices plus: Clothing change before entering; Shower on exit; All material decontaminated on exit from facility.	Primary barriers = All procedures above in combination with full-body, air-supplied, positive pressure personnel suit.	BSL-3 plus: Separate building or isolated zone; Dedicated supply/exhaust, vacuum, and decontamination systems; Other requirements outlined in the text.

Source: from CDC 1993

Primary Barriers

Primary barriers (safety equipment) are designed to ensure the isolation and containment of infectious material and include BSC, enclosed containers, and other engineering controls (e.g., sharps disposal containers and mechanical pipettors). BSCs should be reserved for laboratory activities with potentially infectious agents or for activities that generate from uncontrolled aerosols generated by laboratory activities. These cabinets are specially designed local exhaust ventilation hoods that include high-efficiency particulate (HEPA) air filters. Air from the cabinet work space is HEPA-filtered before it is recirculated back to the interior of the cabinet and/or exhausted to the laboratory or ducted to a dedicated exhaust system. BSCs are categorized into three distinct classes based on differences in specific performance characteristics: Class I, Class II, and Class III. For each class, the type of protection afforded (personal protection and/or product protection) can vary.

Class I BSCs provide a negative pressure, semi-enclosed environment that exhausts air through a HEPA filter back into the laboratory or outside to a dedicated exhaust system (see Figure 7-5). Room air enters the cabinet through a fixed front opening. The magnitude of the air velocity entering the cabinet is designed to prevent microbial aerosols released within the cabinet from escaping into the room. At a minimum, the air flow for Class I BSCs should be adequate to provide a face velocity at the opening of the cabinet of 75 feet per minute (fpm, 0.4 meters per second). These cabinets are not designed to provide purified air to the cabinet work area. It is possible that microbially contaminated air from the laboratory or cross-contamination of cultures within the cabinet work area may result. Therefore, these cabinets should not be

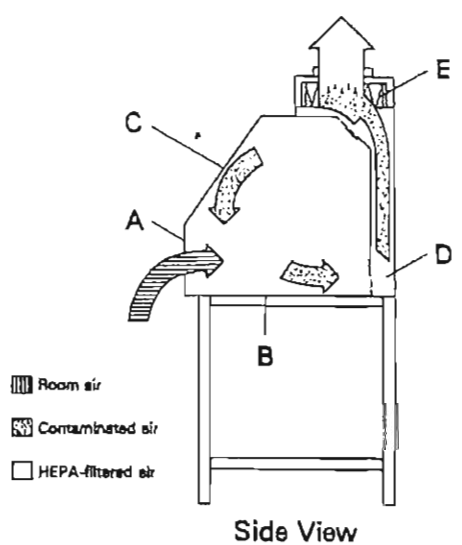

Figure 7-5. *Class I Biological Safety Cabinet* A. front opening; B. work surface; C. window; D. exhaust plenum; E. HEPA filter (adapted from CDC/NIH, 1993).

used for laboratory activities where susceptibility to contamination by other microbial agents exists.

Class II BSCs are most often recommended as a primary containment device. They are designed to protect the inner working environment of the cabinet (i.e., provide a clean airstream for contamination sensitive laboratory activities) *and* significantly minimize the escape of microbial contaminants into the surrounding laboratory. These cabinets are classified into Type A or B as defined by the cabinet construction, airflow velocities and patterns, and exhaust system design. Both types utilize a downward laminar flow of HEPA-filtered air that separates at the working surface to slots in the back and the front of the cabinet (see Figure 7-6).

Type A cabinets use an internal system of ducts, HEPA filters, and a fan to recirculate a substantial portion (up to 70%) of HEPA filtered air back to the cabinet workspace and to exhaust the remaining 30% back into the laboratory. Most Class II, Type A cabinets have dampers to modulate this 30/70 division of airflow. This recirculation makes these cabinets suitable for microbiological activities but not for work with volatile or toxic chemicals and radionuclides. The face velocities of these systems should be maintained at a minimum of 75 fpm (0.4 m/s). It is possible to duct the exhaust from a Type A cabinet out of the building. However, it must be done in a manner that does not alter the balance of the exhaust system, which could result in a disturbance of the internal cabinet airflow or other cabinets attached to the system. The usual method is to use a "thimble," or canopy hood, which maintains a small opening around the cabinet exhaust filter housing (CDC/NIH, 1995).

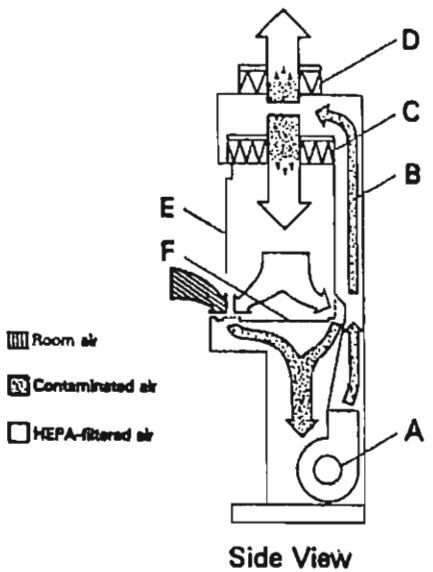

Figure 7-6. *Class III, Type A Biological Safety Cabinet* A. blower; B. rear plenum; C. supply HEPA filter; D. exhaust; E. sash; F. work surface (adapted from CDC/NIH, 1993).

Type B cabinets are similar in design to Type A, however, this cabinet allows for separate exhaust of up to 100% of HEPA-filtered air to the building dedicated exhaust system. Additionally, the plenum is maintained under negative pressure. These modifications ensure that contaminated materials (including toxic chemicals and radionuclides) are contained in the cabinet assembly until exiting the exhaust system. For all Type B cabinets, face velocities should be maintained at a minimum of 100 fpm (0.5 m/s).

To reflect the degree of exhaust to a dedicated, external system, Type B cabinets are further divided into three sub-categories. Type B1 systems recirculate 30% of the air through a HEPA filter back into the cabinet work space with the remaining 70% being exhausted via a separate fan and duct work (see Figure 7-7). Type B2 is a total exhaust cabinet, that is, no air is recirculated (see Figure 7-8). All air from the cabinet work space is ducted to a dedicated exhaust fan. This type of cabinet is expensive to operate since it exhausts large quantities of conditioned room air. If the exhaust fails, this type of cabinet will be pressurized via the supply fan, resulting in a flow of air from the cabinet back into the laboratory. Cabinets built since the early 1980s incorporate an interlock system to prevent the supply blower from operating whenever the exhaust flow is insufficient. Presence of such an interlock system should be verified; existing systems can be retrofitted if necessary. Exhaust air movement should be monitored by a pressure-independent device. Type B3 cabinets are identical to a Class II, Type A cabinet with the exception that the 30% component is ducted to a dedicated exhaust system. All positive pressure contaminated plenums within the cabinet are surrounded by a negative air pressure

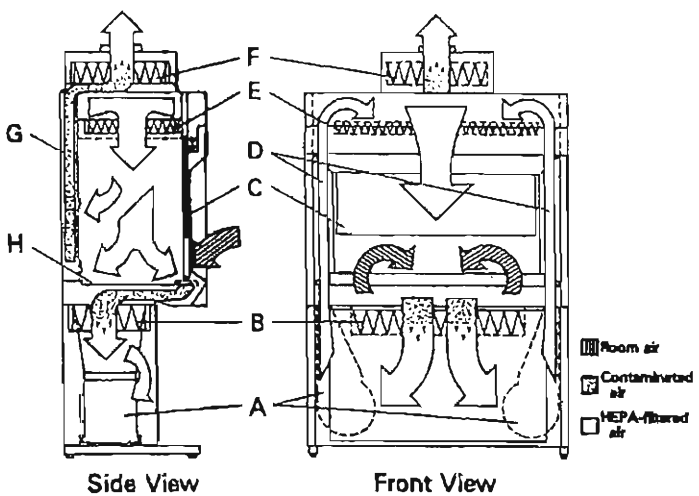

Figure 7-7. *Class II, Type B1 Biological Safety Cabinet* A. blowers; B. supply HEPA filters; C. sliding sash; D. positive pressure plenums; E. additional supply HEPA filter or back-pressure plate; F. exhaust HEPA filter; G. negative pressure exhaust plenum; H. work surface (adapted from CDC/NIH, 1993).

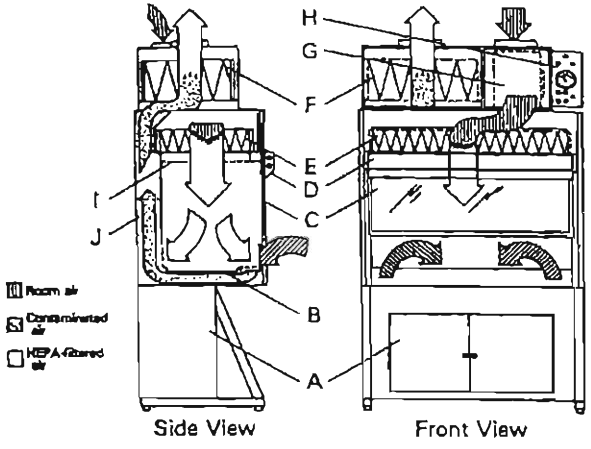

Figure 7-8. *Class II, Type B2 Biological Safety Cabinet* A. storage cabinet; B. work surface; C. sliding sash; D. lights; E. supply HEPA filter; F. exhaust HEPA filter; G. supply blower; H. control panel; I. filter screen; J. negative pressure plenum (adapted from CDC/NIH, 1993).

plenum. Thus, leakage in a contaminated plenum will be into the cabinet and not into the environment. (see Figure 7-9).

It is critical that work practices within the Class II cabinets ensure an unobstructed flow of air to the exhaust slots. Cabinets should never be used to store laboratory materials. Work activities should not be conducted too near the front opening as this could disrupt the clean air sheath that protects the laboratory worker. Additionally, activities around the BSC that could affect airflow into the front slot (thereby breaking the protective containment of the system) should be closely monitored. Disruptive activities may include the repeated insertion and withdrawal of worker arms, supply air diffusers, or cooling fans with focused airstreams in the vicinity of the cabinet, the opening and closing of entry doors, and personnel movements in front of the BSC. In Type B cabinets, since the air that flows to the rear grille is discharged directly into the exhaust system, activities that may generate hazardous chemical vapors or particulates should be conducted towards the rear of the cabinet.

Blowers on exhaust systems should be located at the terminal end of the duct work. A failure in the building exhaust system may not be apparent to the user, as the supply blowers in the cabinet will continue to operate. A pressure-independent monitor should be installed to sound an alarm and shut off the BSC supply fan, should failure in exhaust air flow occur. Since this feature is not supplied by all cabinet manufacturers, it is prudent to install a sensor in the exhaust system as necessary. To maintain critical operations, laboratories using Type B BSCs should connect the exhaust blower to the emergency power supply.

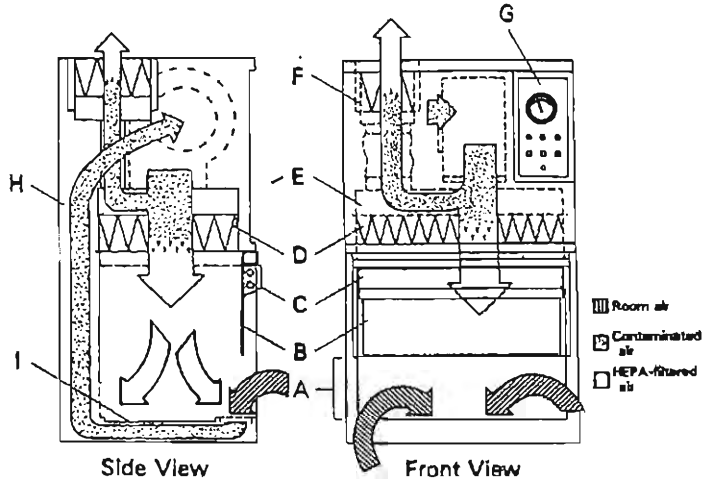

Figure 7-9. *Class II, Type B3 Biological Safety Cabinet, table-top model* A. front opening; B. sliding sash; C. light; D. supply HEPA filter; E. positive pressure plenum; F. exhaust HEPA filter; G. control panel; H. negative pressure plenum; I. work surface (adapted from CDC/NIH, 1993).

Class III BSCs are totally enclosed, ventilated systems that operate under negative pressure. Because these systems are designed to be used with extremely hazardous microbial agents, the seals and their subsequent ability to maintain pressure is integral to the containment performance. Worker access to the cabinet interior is facilitated through rubber gloves attached to ports located on the front (see Figure 7-10). Air entering the cabinet first passes through a HEPA filter. Contaminated air that exhausts the cabinet must pass through two HEPA filters placed in series or a single HEPA filter backed up by an incinerator before being exhausted to the outdoors. Equipment that is used to perform functions within the cabinet must be an integral part of the system due to the containment requirements for working with these extremely hazardous agents (i.e., a gastight enclosure). The entry for equipment into the cabinet is facilitated through sealed air locks; equipment removal must be through a double-doored autoclave (or other decontaminating, air lock systems) or through a "dunk tank" containing a liquid disinfectant.

The critical nature of BSCs in the microbiological laboratory requires that they be constructed according to design specifications and that they meet minimum standards of performance. The National Sanitation Foundation (NSF International) Standard No. 49 for Class II (Laminar Flow) Biohazard Cabinetry provided the first independent standard for design, manufacture and testing of Class II BSCs. Specifically, NSF Standard 49 outlines design, construction, and performance criteria (NSF, 1992). This Standard for biological safety cabinets establishes performance criteria for biological safety cabinets and provides the minimum require-

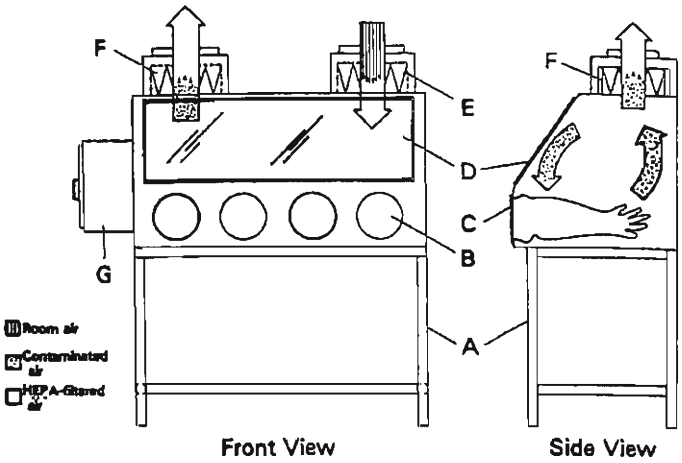

Figure 7-10. *Class III Biological Safety Cabinet* A. stand; B. glove ports; C. O-ring for attaching arm-length gloves to cabinet; D. slopped glass viewing window; E. supply HEPA filter; F. exhaust HEPA filter (second HEPA exhaust is not shown); G. double-ended autoclave (adapted from CDC/NIC, 1993).

ments that are accepted in the United States. Cabinets that meet the standard and were certified by the NSF bear an NSF 49 Seal.

When one buys a Class II BSC, an NSF certification seal should be affixed. Once the cabinet is installed, it becomes the responsibility of the user to maintain the BSC in conformance with the applicable performance criteria. The Class II BSC should undergo a field certification upon installation and at scheduled intervals thereafter. Field re-certification of Class II BSCs should be undertaken on an annual basis, if the cabinet is relocated, or when the HEPA filters are changed. While the NSF standard does not cover field testing of BSCs, it is common for many of its test methods and parameters to be applied in the field, and these are included in Annex "F" of the document. On-site testing following the recommendations for field testing in NSF Standard 49 must be performed by qualified personnel. The NSF maintains a list of companies that manufacture Class II Biosafety Cabinets as well as a list of accredited Field Certifiers (NSF, 1998). Cabinets should contain on the front of their surfaces, explicit statements of certification, limitations regarding cabinet usage, and the next date for re-certification. A list of agents authorized to service the interior of the cabinet should also be kept and prominently posted on the cabinet structure.

All users of cabinets should receive basic training with subsequent periodic refresher courses regarding overall cabinet usage, biological agent manipulation techniques, proper interpretation of cabinet limitation statements (and any subsequent revisions), and certification statements. Periodic review by laboratory management to ascertain adherence to proper BSC

usage, laboratory techniques, and training effectiveness should also be performed. Records regarding cabinet purchase, intended use, agents authorized for manipulation within the cabinet, training documentation, and certification/operational status, should be readily accessible to users and to laboratory management.

Secondary Barriers

Secondary barriers (facility design) provide the next level of control beyond the isolation of the contaminant at the source. These barriers are designed to protect personnel inside and outside the laboratory environment from inadvertent exposures (those uncontrolled by the primary barriers). Additionally, the implementation of more complicated engineering control measures (i.e., ventilation) can minimize the escape of agents into the environment outside of the facility.

The degree of hazard of the infectious agent will dictate the types of controls used. For agents classified for work at BSL 1, specific recommendations for secondary barriers include the availability of handwashing stations; non-porous (i.e., impervious to water) bench-tops or work surfaces that are resistant to acids, alkalis, organic solvents, and moderate heat; and laboratory equipment and furniture (including placement) that facilitate cleaning. For BSL 2 agents, additional equipment suggestions include the availability of autoclaves for the proper decontamination of materials and equipment used in the laboratory.

Higher risk agents and activities require the application of physical barriers to help prevent the migration of contaminants from laboratory work areas to other areas of the facility. However, physical barriers alone cannot guarantee containment. The use of general ventilation to create pressure differentials (i.e., with respect to adjacent rooms) between activity zones will minimize opportunities for contaminant escape when doors are opened. BSL 3 recommendations include the physical separation of the laboratory work environment from access corridors. Additionally, access points should be designed with two sets of self-closing doors to act as a "buffer" zone between contaminated and clean areas. Dedicated, ducted exhaust and supply ventilation systems are used to create the negative pressure differentials necessary to move air from clean to contaminated areas. The exhausted air should be discharged outside away from points where re-entrainment of contaminated air could occur (i.e., outdoor air intakes, entry doors, and windows) or away from locations that are occupied. At no time should the exhaust air be recirculated to other areas of the building. Filtration or other means of decontamination may be applied before exhausting the air.

Due to the extremely hazardous nature of work with BSL 4 agents, the requirements for laboratory facilities include very stringent design criteria regarding isolation and containment. Laboratory work areas should be physically-separated from other activities by means of a dedicated building or isolated zones that have been clearly identified. Laboratory personnel accessing or exiting the laboratory must do so through changing rooms separated by a shower facility. All access doors should be self-closing and lockable. All penetration points in the structural envelope of the facility must be tightly controlled. The construction of walls, floors, and ceilings should be done in a manner that forms a sealed shell that facilitates cleaning and decon-

tamination (i.e., fumigation) and eliminates the possibility of animal or insect intrusion. Windows should be resistant to breakage. Other penetration points for consideration include water drainage lines and ventilation lines (e.g., sewer vents). Water drainage line traps should be filled with demonstrably effective chemical disinfectants as a means to seal potential escape routes. Similarly, ventilation exhaust lines should be equipped with HEPA filters.

Materials, supplies, and equipment that are not transported into or out of the laboratory via the changing rooms must pass through double-door autoclaves, fumigation chambers, or ventilated air-locks. Similarly, all materials must be decontaminated before removal from the laboratory environment either through double-door autoclaves or, for materials that cannot be autoclaved, pass-through dunk tanks, fumigation chambers, or other decontamination systems. Liquid effluents (excluding those from the showers and toilets) must be decontaminated through physically and biologically validated heat treatment systems. After decontamination, effluents may be discharged to the sanitary sewer.

Ventilation systems used to supply conditioned air to the laboratory work environment, as well as exhaust air (general removal systems or those ducted from the BSCs) should be dedicated exclusively to the BSL 4 laboratory. Air that is exhausted from the laboratory should never be recirculated back into the work space or any other part of the facility. Additionally, the placement of exhaust exit points should be in locations that guard against re-entrainment of air into the building, e.g., through ventilation system air intakes outdoors. Although ventilation lines are equipped with HEPA filters, system integrity failures can occur (e.g., filters may have slipped off of the seal or there could be breaks in the filter material). These could cause contaminated air to enter the building. Ventilation systems should be balanced in a manner that moves air from clean to less clean or contaminated areas. This includes negative pressure differentials created between the laboratory and designated, uncontaminated areas of the building, and from designated low risk areas to areas of greater potential risk. It is critical that personnel involved in the maintenance and operation of the ventilation system recognize that any change in a component of the system can have a dramatic effect on the pressure relationships between adjacent locations. A component may include the exhaust fans, central HVAC units, dampers, and/or doors and windows. For this reason, access to the ventilation systems (i.e., exhaust fans and HVAC units) should be given to designated personnel only. Monitoring systems should be installed that include alarms that indicate malfunctions of the system. Interlocks between the supply and exhaust systems can help ensure that negative pressure (or minimally a neutral pressure differential) is maintained. Regular preventive maintenance and monitoring is critical to the continued containment capabilities of the system.

In those circumstances when the laboratory work activities limit the practicality of Class III BSCs, a specially designed room or environment can be used along with the use of specially designed PPE as a component of the primary barrier system. One-piece positive pressure suits are worn by personnel entering the containment area. These suits encapsulate the worker and are ventilated with fresh air from a life support system. The supplied air should be clean, low humidity, conditioned (i.e., cool), and free from oil. Backup systems should be incorporated into the life support system in case of equipment failure with alarms to indicate to the wearer

that failure has occurred. Access to the containment area is gained through an airlock fitted with airtight doors. The availability of a chemical shower allows decontamination of the environmental suit exterior prior to exit. The shell of the containment area is designed as a large BSC Class III cabinet, i.e., exhausted air must pass through two HEPA filters placed in series or must be incinerated. All materials leaving the containment area must be properly decontaminated (e.g., through double-doored autoclaves, fumigation chambers, or chemical dunk tanks). The room must be operated under negative pressure, and interlocks must be installed between the supply and exhaust ventilation systems to ensure that negative (or neutral) pressure is maintained. Work activities within the containment area should be conducted in Class I or II BSCs, even with the protection afforded by the encapsulating environmental suit.

More detailed discussions may be found in the CDC *Biosafety in Microbiological and Biomedical Laboratories*, the American Society for Microbiology *Laboratory Safety: Principles and Practice*, and the American Industrial Hygiene Association *Biosafety Reference Manual* (Fleming et al., 1995; Heinsohn et al., 1995).

NON-INDUSTRIAL INDOOR ENVIRONMENTS

Unlike the health care industry where the disease and, subsequently, the etiologic agent is identified, the nature and extent of health outcomes resulting from exposures to microbiological agents in indoor environments have not been well defined. This makes the assessment and control of microbiological contamination a difficult process. Difficulties arise from the diverse nature of the causative agents, the variability of the airborne concentrations of the organisms, the sensitivity and reliability of the evaluation tools, and the lack of a clear dose-response relationship between exposures and health effects, and the variation in susceptibility among those exposed. However, the collection of appropriate and sufficient information by various members of an investigation team (including clinicians, epidemiologists, and environmental consultants, i.e., industrial hygienists) will suggest plausible hypotheses regarding the existence of microbiological reservoirs and their potential effect on the population. These hypotheses can then be tested through the collection of environmental data, health questionnaires, and/or clinical tests. Information must be collected with consideration of the determinants of bioaerosol health effects and their interactions. The likelihood and severity of adverse health effects from bioaerosol exposure depend on (a) the biological materials present; (b) the concentrations in air of such materials, preferably at the time of the exposure that caused the effect; (c) the disease outcomes associated with exposure to the bioaerosols; and (d) the general health and immunologic status of the exposed individuals.

The findings from the initial investigation may result in a re-evaluation of the original hypotheses, with the possible collection of additional data. The collected information can reveal environmental conditions suitable for microbiological growth, the location of microbiological reservoirs, and possible dissemination mechanisms. During the initial investigation, the search should focus only on those agents that can be associated with the reported health effects.

For example, in identified clusters of legionellosis, the investigator would not conduct an investigation in search of fungi, dust mites, or other aeroallergens. All of the collected information is subsequently collated and critically analyzed towards the development of recommendations including the remediation of current microbiological reservoirs and the control of future contamination.

The necessary elements of microbiological proliferation are the presence of the biocontaminant; the susceptibility of a material to contamination by microorganisms, nutrients, and moisture; and the appropriate environmental conditions (i.e., temperature and humidity) for the growth of the specific microorganism. Many biocontaminants are ubiquitous inhabitants of the human environment, and therefore, their presence must always be assumed. Material susceptibility to microbial colonization is a function of its porosity. Increasing the number and/or size of pores increases the available surface area for the deposition of particles containing organic debris and hinders cleaning of the surface. Additionally, porous materials more easily absorb moisture. A suitable localized environment (i.e., having adequate nutrients, available moisture, and an appropriate temperature) when combined with highly porous materials, provides optimum conditions for microorganisms to grow. For example, interior duct lining downstream of the ventilation system cooling coils is highly porous. Low efficiency filters upstream of the coils allow the passage of particles that are deposited in the duct lining. In addition, water-saturated air downstream of the coils (caused by the reduction of the air temperature down to, or below, the dew point) condenses onto metal ducting and is absorbed into duct lining. The result is often the growth of fungal colonies in the interior of the ventilation system.

Nutrient sources for bacterial or fungal growth are common in the indoor environment. Examples include accumulated dirt on the insides of ventilation ducts; wood and paper products such as books, cardboard containers, wallpaper, and gypsum wallboard; and other plant and animal materials such as cotton fabrics, wicker baskets, jute carpet backing, sloughed skin cells, and leather. Housekeeping activities and improved ventilation system filtration can help to reduce the deposition and accumulation of particles on surfaces. As stated above, microbial growth and survival also depend on the water activity of the substrate. Water activity is defined by the vapor pressure exerted by the moisture in the material, expressed as a percentage of the saturation vapor pressure of pure water at the same temperature (Flannigan, 1992). Fungi are grouped by their preference for high or low amounts of available water, described, respectively, as hydrophilic, mesophilic, xerotolerant, and xerophilic (Burge, 1995). The documentation of water incursion (either chronic, intermittent, or as an isolated event) can direct a search for microbial reservoirs to damp or water-damaged areas of a building. Microorganisms are also grouped according to their temperature preferences or tolerances, e.g., bacteria are described as psychrophilic, mesophilic, thermotolerant, or thermophilic, respectively, from low to high temperature preference.

Information regarding the moisture content of building materials and/or the relative humidity and temperature within a building may help investigators anticipate what kinds of microorganisms may be present. Su et al. found an association between certain groups of fungi

and environmental factors (e.g., soil fungi in homes with dirt-floor crawlspaces; hydrophilic fungi in homes with collected water; and above-ground decay fungi in homes using gas stoves, which may add moisture to the indoor air and encourage people to ventilate their homes with outdoor air) (Su et al., 1992). Similar research may direct attention to particular environments in the search for certain microorganisms and, conversely, may clue investigators to look for certain bioaerosols and related health effects when they notice specific environmental conditions.

Control

The control of moisture incursion, nutritional substrates, and/or temperatures to appropriate levels in the indoor environment will decrease the ability of microorganisms to proliferate. However, microbes are known to survive (even thrive) extreme temperature variants. For example, *Aspergillus fumigatus* has been shown to have a temperature growth range of 12-52°C (Cooney and Emerson, 1964). Therefore, it appears unlikely that the indoor environmental temperature in the occupied spaces can be controlled so as to significantly affect the proliferation of most microorganisms. Given the abundance of nutrient rich media in indoor environments, the exclusion of which also appears unlikely, moisture incursion remains the only practically affectable control factor. To be effective, the investigator must be conscious of water incursion in two forms, liquid and vapor, and how these forms penetrate the building envelope.

Moisture can pass through the building envelope by one or more of four transport mechanisms: 1) liquid flow, 2) capillary action, 3) air movement, and 4) vapor diffusion (Lstiburek and Carmody, 1994). Each transport mechanism can produce unique communities of microbial contamination in specific building locations depending on the frequency of the water intrusion, the quantity of water, and the micro-climate into which it is introduced. For example, ground water intrusion through basement foundation cracks can introduce large "flooding" quantities of water resulting from hydrostatic pressures on the building exterior. These hydrostatic pressures are generally associated with high ground water tables (e.g., resulting from heavy rain). This type of intrusion is predominantly intermittent. However, if the problem is not promptly remediated, the quantity of moisture remaining can promote the growth of hydrophilic fungi (e.g., *Fusarium* sp. and *Stachybotrys chartarum*), yeasts, and Gram negative bacteria. On the other hand, water vapor (i.e., high relative humidity) introduced through a ventilation system's outdoor air intakes can moisten porous interior duct liners providing suitable environments for fungal growth. Martinez et al., in a study of a large office building with a microbiologically contaminated ventilation system, identified inherent system design flaws (improper cooling coil temperature, low-efficiency filters, and porous duct lining) that permitted the development, amplification, and dissemination of microorganisms (predominantly *Penicillium* species) (Martinez et al., 1995). The moistened material and cool temperatures induced by the cooling coils in the ventilation systems selected for psychrotolerant and mesophilic (moisture) and/or xerotolerant species (e.g., *Penicillium* and *Cladosporium*). Carpets installed onto concrete slab

flooring provide a niche for summer mold growth when water vapor condenses on the concrete and carpet backing.

The structural design of the building envelope will have the greatest effect on the amounts of moisture incursion. Significant intrusion points can occur at foundation cracks, through openings in exterior walls (i.e., around doors and windows and through the vapor barrier), and at breaks in the roof. Liquid flow and capillary action can occur at all penetration points of the building envelope including foundations, exterior walls, and roofs, and is generally the result of groundwater, rain, or snow melt. Moisture intrusion through air movement is predominantly governed by air pressure relationships induced by the building ventilation system. Moisture-laden air enters through the outdoor air intakes or through cracks in the building envelope via ventilation-induced negative pressures. Air pressure differentials in a building can also be induced by the stack effect — air movement caused by vertical thermal convections in a building — and by pressures induced by wind on outside building surfaces. Vapor diffusion into a building occurs as a result of the inappropriate installation of vapor barriers in exterior walls or around the foundation.

The application of specific moisture controls varies according to the transport mechanism. Liquid flow and capillary action are minimized by the application of deterrents or barriers that prevent water migration through breaks in the building envelope structure. For example, ground water intrusion can be controlled with the use of drainage systems that reduce the hydrostatic pressure around building foundations coupled with exteriorly applied moisture resistant coatings. Rain water intrusion is reduced by the appropriate application of drainage screens, flashing, gutters, and downspouts. Capillary action is a consequence of the surface tension of a liquid between two closely spaced adjacent materials, e.g., two panels of wood siding. By controlling the available capillary moisture, sealing of the capillary pores or making them larger, or providing a receptor of the capillary moisture, the amounts of moisture intrusion by this mechanism can be minimized. These types of water incursion are generally not limited by the climatic conditions of different geographic areas. The design concepts should control ground and rain water intrusion without regard to temperate zones (i.e., heating, cooling, or mixed climates). However, the mechanisms of air movement and vapor diffusion are controlled or influenced by the local climatic conditions.

Buildings are designed to protect the occupants from the elements outdoors. However, geographical regions throughout the United States exhibit distinct climatic conditions and building designs should be adjusted accordingly. A simplified categorization system that can be applied to moisture control is based on the geographically predominant environmental control system shown in Figure 7-11. Architectural design concepts (regarding vapor diffusion) that are used in the northern climates (ventilation defined heating zones) should not be used for building designs in the southern regions (ventilation defined cooling zones). The climate zone has been defined according to the number of heating degree days or hours of wet-bulb temperature. A recommendation for heating zones is defined by 4000 heating degree days (base of 65°F [18°C]) or more. Cooling zones (warm, humid climates) are defined by 1) 3000 or more hours during

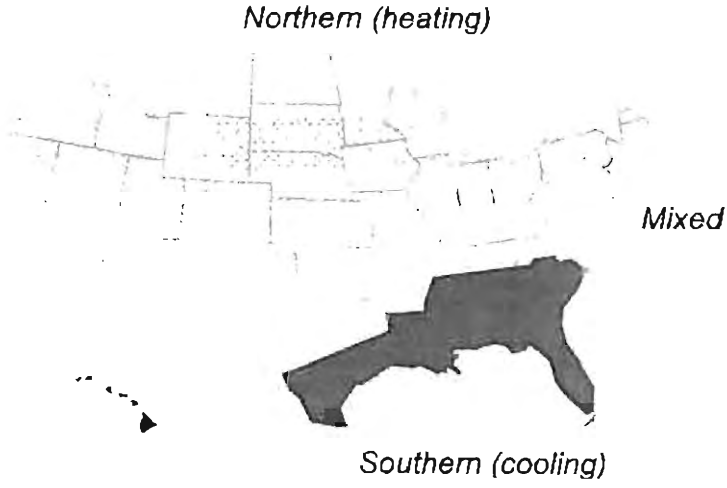

Figure 7-11. Climate zones used for moisture recommendations (adpated from Lstiburek and Carmody, 1994).

the warmest six consecutive months of the year of 67°F (19°C) or higher wet-bulb temperature and/or 2) 1500 or more hours during the warmest six months of the year of 73°F (23°C) or higher wet-bulb temperature. Mixed zones fall within those not defined as heating or cooling.

Vapor-retarding systems are usually installed at or near the surface that is exposed to higher water vapor pressure (Pope et al., 1993). In the northern climates, these systems are normally applied to the interior surface of the envelope wall space in front of the insulation (higher vapor pressure generally occurs in the occupied spaces) (ASHRAE, 1997). This practice controls the ex-filtration of moisture laden interior air out through the exterior wall. Applying the same technique in a southern climate can result in moisture condensation at this surface because water vapor is migrating from outdoor (humid) locations into the interior spaces. The resultant moisture availability, combined with the building materials (i.e., paper of the gypsum board), provides an environment conducive to the growth of microorganisms. Therefore, in the southern regions in air-conditioned buildings, vapor-retarding systems should be applied to the exterior surface of the envelope (higher water vapor pressure exists outdoors). These differences in design also apply to air movement. Positively pressurizing a building in a southern climate will ensure that moisture laden air will not infiltrate the interior of a building. In the northern climates, buildings should operate under a neutral or slightly negative pressure, however, this may enhance the infiltration of contaminants that are detrimental to the indoor environment (e.g., products from combustion appliances, radon gas emitted from soil, outdoor fungal spores, etc.).

Remediation

Remediation of microbially-contaminated building surfaces will result in the disruption of microbiological reservoirs. The airborne dissemination of these bioaerosols can pose a significant exposure concern for the remediation workers. Additionally, these aerosols can be spread to uncontaminated areas of a building, increasing the hazard for the remaining occupants and adding to the difficulty of clean-up. Therefore, it is important that all remediation activities be conducted with an awareness of the potential bioaerosol exposures and with minimal disturbance of contaminated materials. Specifically, controls must be instituted that protect both the *worker* and the *adjacent environment.*

Given the level of disruption that may occur during microbiological remediation work, engineering controls applied at the source should be the primary control measure. Remediation activities should be conducted in a manner that minimizes the disturbance of microbiological reservoirs. However, as the extent of the microbial contamination becomes larger, reservoir dissemination becomes unavoidable due to the removal of building materials. Under these conditions, isolation barriers are required to contain airborne spores and other biological matter. Barriers alone disrupt the pathways between remediation zones and adjacent environments, but disseminated aerosols almost invariably find breaks in any barrier system. Therefore, negative pressure relative to adjacent areas is induced in the remediation zone to ensure containment. It is critical that the exhausted airstreams be appropriately filtered (i.e., HEPA filters) to guard against the re-entry of microbially-contaminated air back into the zone of remediation and/or to other areas that are considered uncontaminated.

Specific control guidelines have been recommended by the New York City Department of Health (NYCDH) for the remediation of fungi from contaminated building materials (see Table 7-5) (NYC Dept. of Health, 2000). The recent revision of the guidelines was intended to be inclusive of all fungi as opposed to the 1993 version, which only focused on *Stachybotrys chartarum*. The expansion to other fungi was based on the following: (1) *Stachybotrys chartarum* cannot be considered as uniquely toxic in indoor environments since many fungi produce mycotoxins, some of which are identical compounds; (2) individuals engaged in remediation activities of widespread fungal contamination may be at risk of developing organic dust toxic syndrome or hypersensitivity pneumonitis; and (3) fungi can cause allergic reactions. These guidelines define five levels of abatement characterized by the scale of the contaminated surface area. All remediation efforts should be conducted during unoccupied periods. Remediation workers should be properly trained in the potential health hazards, appropriate work practices, and correct use of engineering measures. Appropriate PPE should be worn by those individuals involved in all aspects of clean-up activities. Workers should be medically cleared.

Under the NYCDH guidelines, Level 1 abatement requires minimal engineering control measures (other than the use of dust suppression techniques), and relies predominantly on worker practices of appropriately trained building maintenance staff to minimize the disturbance and subsequent airborne dissemination of fungal spores. Contaminated materials should be sealed in plastic bags and disposed of as sanitary waste (Morey, 1993). Level 2 abatement employs

Table 7-5
Suggested guidelines for the remediation of fungi

Abatement Level	Extent of Microbial Contamination	Remediation/Isolation Level
1	< 10 ft²	Work performed by trained maintenance staff in unoccupied area. Use of N-95 respirator, gloves, and eye protection. Containment unnecessary; dust suppression methods recommended. Damp wiping of surfaces. Contaminated materials removed in sealed plastic bags.
2	10 to 30 ft²	Work performed by trained maintenance staff in unoccupied area. Use of N-95 respirator, gloves, and eye protection. Work area covered in plastic and sealed with tape. Dust suppression methods recommended. Work and egress areas HEPA vacuumed and cleaned. Contaminated materials removed in sealed plastic bags.
3	30 to 100 ft²	Health and safety professionals consulted. Remediation personnel properly trained in the handling of hazardous materials. Use of N-95 respirator, gloves, and eye protection. Work area covered in plastic and sealed with tape. Seal ventilation ducts and grills. Dust suppression methods recommended. Work and egress areas HEPA vacuumed and cleaned. Contaminated materials removed in sealed plastic bags. For dust generation move to Level 4.
4	> 100 ft²	Health and safety professional consulted. Remediation personnel properly trained in the handling of hazardous materials. Use of full-face, HEPA filtered respirators; full-body covering; and gloves. Complete isolation of work area with critical barriers, negative pressure, airlocks, and decontamination room. Contaminated materials removed in sealed plastic bags (outsides must be HEPA vacuumed or damp wiped). Work and egress areas HEPA vacuumed and damp wiped. Air monitoring should be conducted.
5 (HVAC)	< 10 ft²	Work performed by trained maintenance staff in unoccupied area. Use of N-95 respirator, gloves, and eye protection. Work area coveredin plastic and sealed with tape. HVAC system shut down. Dust suppression methods recommended. Contaminated growth supporting materials removed in sealed plastic bags. Workand surrounding areas HEPA vacuumed and cleaned.
	> 10 ft²	Health and safety professional consulted. Remediation personnel properly trained in the handling of hazardous materials. Use of N-95 respriator, gloves, and eye protection; for > 30 ft², use of full-face, HEPA filtered respirators; full-body covering; and gloves. Complete isolation of work area with critical barriers and negative pressure; airlocks and decontamination room for > 30 ft². Contaminated materials removed in sealed plastic bags (outsides must be HEPA vacuumed or damp wiped). Work and egress areas HEPA vacuumed and damp wiped. Air monitoring should be conducted.

Adapted from New York City Department of Health, 2000

engineering measures (i.e., polyethylene enclosures) to contain spore dissemination. Additionally, the work and egress areas require cleaning with HEPA-filtered vacuum equipment prior to the application of detergent solutions. Level 3 requires that remediation be conducted by specialized individuals who have been trained in the handling of hazardous materials. All work areas and those directly adjacent should be covered with polyethylene sheeting and taped (i.e., sealed) including ventilation supply and exhaust grills/diffusers. If the abatement procedures are expected to generate considerable dust or visible fungal contamination is heavy, then Level 4 procedures should be instituted; a health and safety specialist experienced with microbiological agents should be consulted in addition to the use of remediation workers trained in the handling of hazardous materials equipped with appropriate PPE. Appropriate PPE includes full-face respirators with HEPA cartridges, full-body disposable clothes covering, and gloves. The design of containment structures should be comprehensive including total enclosure, exhaust ventilation through HEPA filters to create negative pressure, airlocks, and a decontamination room. Air monitoring is recommended prior to re-occupancy.

Level 5 remediation protocols apply to HVAC systems. The protocols for contaminated areas less than 10 ft^2 (0.9 m^2) are similar in concept to Level 2 remediation activities. Additionally, it is recommended that the ventilation system be shut down prior to work and that contaminated porous materials be removed. For HVAC systems with contamination greater than 10 ft^2 (0.9 m^2), abatement includes combinations of engineering measures, worker practices, and administrative controls similar to Level 4 remediation protocols to ensure fungal spore containment during remediation activities. Isolation barriers are constructed of polyethylene walls; containment is maintained with HEPA-filtered fans that exhaust to the outside. The handling of contaminated materials is conducted in a manner consistent with the handling of hazardous chemicals to ensure the protection of the remediation workers and adjacent environment.

Remediation workers should use PPE appropriate for the hazards to which they may be exposed. Such decisions require *a priori* awareness of potentially hazardous agents, significant exposure routes (e.g., inhalation, dermal contact, or ingestion), and possible concentrations of the biological materials. For example, disturbance of obvious fungal growth and large accumulations of organic matter (bird, bat, or rodent droppings) can be a significant exposure risk for remediation workers. Even the inspection and/or collection of water samples from operating cooling towers in legionellosis investigations can place investigators at risk of exposure. The first step in risk assessment is a visual evaluation of the possible type and extent of contamination, subsequently leading to a determination of the level of protection needed. For example, remediation work on small, localized patches of mold growth on ceilings or walls should be conducted with appropriate respirators, eye protection, and gloves. In contrast, investigators entering an attic with large accumulations of bird or bat droppings may need full-face, powered air-purifying respirators, disposable protective clothing with hoods, gloves, and disposable shoe coverings (see Figure 7-12) (Lenhart, 1994).

In many circumstances, a disposable N-95 NIOSH-approved respirator should offer adequate protection provided that the facepiece fits tightly, ensuring that contaminants do not

Figure 7-12. PPE for remediation workers removing bird or bat droppings.

enter through leaks between the respirator and a wearer's face. (The N-95 designation indicates that the filter material has been shown to remove 95% of particles greater than 0.3 μm.) The size of airborne fungal spores generally ranges from 1 to 50 μm. Other bioaerosols generally fall within a similar size range. A relatively intense exposure is usually necessary to affect non-sensitized individuals. However, some environments may require a higher level of PPE due to the concentrations of the microbial agents and their disease potential. Lenhart et al. has developed a work practice and PPE selection guideline for remediation workers involved in the removal of material potentially contaminated with *Histoplasma capsulatum* (Lenhart et al., 1997).

Various levels of "clearance" sampling may provide information on the quality of the remediation efforts. Results from air sampling can be evaluated by comparing those from the remediated areas to those from adjacent areas and outdoor locations. Sampling can include the collection of bulk, surface, and/or air samples for the suspected etiologic agent(s). However, due to the lack of health-based exposure criteria and the limitations of microbiological sampling protocols, the interpretation of the sampling results is complicated. Establishing acceptable residual concentrations after remediation activities ideally requires risk assessment procedures that include knowledge of the possible clinical endpoints (i.e., infectious, allergic, or toxigenic) and their disease severity, as well as the contribution from outdoor sources and viability of the suspected agent. However, if workers have been immunologically sensitized they may not be able to return to a workplace that has been characterized as sufficiently "clean" for

the non-sensitized worker. Bulk and surface samples are collected to identify the predominant taxa of bacteria and fungal contaminants on source materials. In certain situations, air samples can be collected to document the continued airborne presence of a suspect microbial contaminant.

GENERAL INDUSTRY

Agriculture

The contribution of microorganisms to adverse occupational health outcomes is well-recognized, especially in agriculture. "Farmer's lung" has been associated with exposures to various grain saprophytes, including thermoactinomycetes and thermotolerant fungi (e.g., *Aspergillus* sp.), and also mites (Schenker et al., 1998; Kotimaa et al., 1984; Taylor, 1987). These microorganisms are ubiquitous inhabitants of the environment and thrive in the presence of abundant organic substrates found during the harvest season (and during the storage of grains) and suitable amounts of moisture. The magnitude and specific nature of the agricultural activities (i.e., the use of heavy farm machinery such as harvesters that can generate large concentrations of airborne dust) limit the application of source control measures. In these instances, isolation strategies can significantly reduce the occupational exposures to the machine operator. Tractor cabs equipped with HEPA-filtered ventilation systems have been shown to reduce the outdoor air concentrations of particulates by a factor of greater than 100 for particles larger than 1.4 μm in diameter (NIOSH, 1997a, 1997b). However, the efficacy of cab filtration may be hindered by work practices such as frequent door opening and carrying of dust into the cab on work clothes. Where isolation is not a practical alternative, particulate respirators equipped with a minimum of NIOSH certified N95 filters can help to reduce the inhalation of antigenic materials by the worker. Higher levels of respiratory protection may be appropriate for environments that pose increased risks to the occupational population.

Post-harvest, drying of crops before storage can help to reduce the ability of microorganisms to develop a growth niche. The moisture content of storage materials will impact the diversity of the microbial community, i.e., moist grains may contain a greater proportion of thermotolerant and thermophilic microorganisms including *Aspergillus* sp., *Micropolyspora* sp., and thermoactinomycetes (NIOSH, 1986). Additionally, properly ventilated storage bins can limit the available moisture. It has been suggested that the addition of 1% propionic acid can inhibit microbial colonization and limit increased temperatures that select for thermoactinomycetes.

Automated agricultural processes may be more amenable to the application of source control measures. The focused pathways of the process materials during transport and the physical barriers created by the process equipment limit the aerosol generation points. During an evaluation of a sugar beet manufacturer, the installation of LEV over the beet slicers and conveyor belt system was found to significantly reduce the airborne concentrations of total dust and bacteria (Forster et al., 1989). A subsequent decrease in the specific IgG antibody titers of

exposed workers was also observed after the installation of the ventilation system. In a separate study of a sugar beet refinery, high exposures to species of *Aspergillus*, *Penicillium*, and *Cladosporium* were identified in pellet loaders and pellet silo workers (Jensen et al., 1993). Subsequent control recommendations included a redesign of the silo to enhance product turnover, modification of the pellet conveyor to prevent spillage, the incorporation of ventilation to control dust from the conveyor, and the use of ventilated spouts during truck and railroad car filling operations.

Animal confinement buildings have been shown to pose significant exposure risks to a diversity of antigenic materials including microorganisms (Cormier et al., 1990; Donham et al., 1989; Jones et al., 1984; Clark et al., 1983; Kullman et al., 1998). The microorganisms observed in confinement buildings are predominately composed of bacteria in contrast to grain handling processes, which have a higher proportion of fungal spores. As with grain handling, source control strategies are limited. Dust control measures may include improved management priorities (e.g., lower stock densities), contaminant dilution through the application of ventilation, and the use of respiratory protection (Donham, 1993). Respirator selection is dependent on the anticipated exposures. Full-face piece respirators with high efficiency filters have been recommended for poultry workers during poultry-catching activities due to levels of bacterial endotoxin encountered (Lenhart, 1998). These respirators have the advantage of affording protection to the eyes in addition to purifying the inhaled air. In those instances when the poultry workers elect to use half-face respirators, eyecup goggles should be provided. Combinations of particulate and ammonia filter cartridges may be appropriate for environments that have demonstrated high levels of ammonia.

The type of feed delivery systems used in animal confinement buildings can have a significant effect on the contribution of dusts from the feed materials. Pelleted feeds have been shown to produce lower dust concentrations than dry meals or wet slurries (Crook et al., 1991). Floor feeding, high moisture feed corn, and indoor feed grinding have resulted in high total and respirable dust concentrations in pig confinement buildings (Holness et al., 1987). Automatic feed delivery systems have been suggested to contain dusts (Myers, 1998). Limited success has been reported with dust suppression systems. The application of a water spray has been shown to reduce the aerosol concentrations in turkey rearing confinements (Cravens et al., 1981). In another study, the addition of a small amount (up to one quart) of water to hay bales prior to their being chopped into material for dairy cow bedding reduced dust and specific dust component concentrations five-fold (Jones et al., 1995). Oil misting systems have been shown to reduce the dust levels in swine confinement buildings by 50%. These systems typically use a 0.5% oil-in-water emulsion automatically misted 12 times per day for 12 seconds at a rate of 7 gallons of oil per pig per day (Nonnenmann et al., 1999). However, such water additive treatments may be ineffectual during freezing weather. Additionally, the introduction of water into an organic-rich environment will increase the potential for the growth of many microbial species (i.e., Gram negative bacteria and hydrophilic fungi).

Biotechnology

The etiologic agents of disease may be contaminants that have found a suitable environment to proliferate in (as in agricultural environments) or may consist of an active component of the manufacturing process. Topping et al. documented sensitization among workers in a biotechnology plant producing citric acid using *Aspergillus niger)* (Topping et al., 1985). The results of this study indicated that the risk was not only from exposures to fungal spores, but also to proteinaceous products found in the culture fluid. In the pharmaceutical industry, Lagier et al. identified a case of occupational asthma in a worker exposed to penicillamine (Lagier et al., 1989). The primary occupational biological hazard in the biotechnology industry is the potential for process microorganisms and their metabolic products to produce an immunologic response in susceptible individuals. Intermediate processing chemicals used during the manufacture of specific products of biotechnology can also pose occupational exposure hazards (e.g., amyl acetate used to extract penicillin).

The effective containment of the potential hazards in the biotechnology industry is dependent on the equipment designs employed in existing chemical process technology. The equipment designs must provide for containment of the microorganisms (viable and non-viable forms), biologically active products or intermediates, and processing chemicals such as extraction solvents. The level of containment is determined by the anticipated risks associated with these agents. Specific factors affecting containment include the selection of appropriate fermentor and associated equipment, suitable exhaust gas treatment, design considerations for vessel overpressurization and relief, suitable inoculation and sampling systems, and the collection and inactivation of condensate that may contain viable microorganisms (Van Houten, 1990).

Anticipating this reliance on chemical process technology, a 1988 study characterized the engineering controls used in conventional enzyme fermentation processes (Martinez et al., 1988). Sample locations selected to reflect worker exposures to process microorganisms included the laboratory (where culture transfers were conducted), inoculum and fermentor tanks (sample ports and agitator shafts), filtering operations, and background locations. The study results indicated that controls are most needed around high-energy operations, including separation equipment (i.e., filters and centrifuges), fermentor agitator shafts, and manual sampling ports (see Figure 7-13). These operations may not be amenable to complete sealing, enclosure, or isolation. Significantly lower bacterial concentrations were observed at a rotary vacuum drum filter compared with concentrations at the filter press. These differences appeared to have resulted from the application of local exhaust ventilation, the inherently better containment characteristics of drum filters, and operator work practices (dislodging filter cake from the filter press plates at the end of each cycle). Rotary vacuum drum filters have been reported to be the most widely used filter in the fermentation industry (Belter, 1979). In contrast, a centrifuge would be expected to produce large concentrations of microbial aerosols. However, as reported in the enzyme manufacturing study, effective process enclosure and the application of local exhaust ventilation at the biomass discharge point resulted in bacterial concentrations significantly below those of the filter process (although above those of the rotary vacuum drum filter). Alternative methods of solids removal include precipitation, coagulation and floculation, chro-

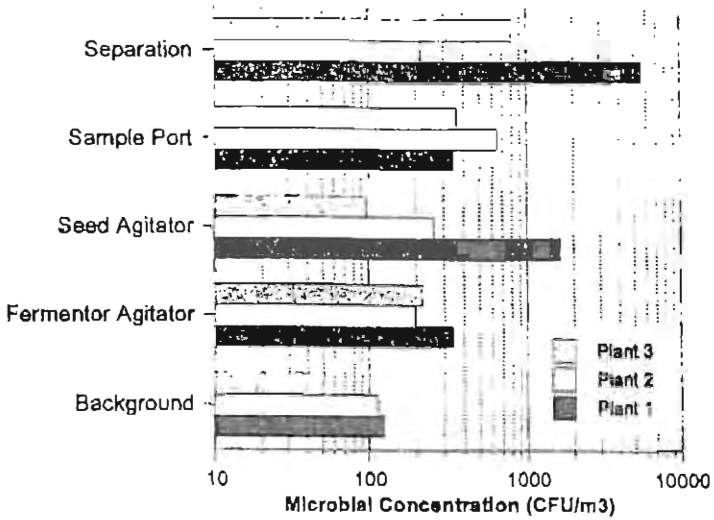

Figure 7-13. Airborne bacterial concentrations at select unit processes in enzyme manufacturing operations.

matography, electrophoresis, and ultracentrifugation. These methods should be applied only after consideration of the agent risk and the inherent containment abilities of the technology. Rapid advancements in the biotechnology industry and use of microorganisms that pose significantly increased risks have resulted in large-scale equipment that offers improved containment capabilities. A study of biohazards associated with using a large-scale zonal centrifuge on oncogenic viruses indicated minimal risks to laboratory personnel during optimal operation (Baldwin et al., 1975). However, faulty seals did result in the detection of high concentrations of phage in the turbine air exhaust and the seal coolant system.

Exhaust gases from the fermentor tanks can be another major emission source of the production microorganisms. The aeration of fermentor broths produces a foam on the surface of the liquid that results in the continuous bursting of bubbles. It has been demonstrated that the droplets of dilute solutions formed by the bursting of bubbles can enrich the concentration of microorganisms by factors of 10 to 1000 times (Blanchard and Syzdek, 1982; Wangwongwatanta et al., 1990). The control of vented bioaerosols within the fermentor tanks produced by this and other mechanical aerosolization processes is achieved primarily by the application of sterilizing (i.e., high efficiency) filtration systems proceeded by "roughing" systems (e.g., cyclones, scrubbers, and/or condensers) (Sayer et al., 1994). Data from the enzyme manufacturing study revealed that scrubbing systems alone may not be effective in controlling vented bioaerosols from the fermentors. The seals around the agitator shafts may be another emission source for the

process microorganisms. Double mechanical steam seals appear to provide inherently better containment than packed seals.

The work practices of the operators can also be a determining factor in the potential for occupational exposure. Duiring the collection of fermentor tank sample volumes in the enzyme manufacturing study, operators were observed purging the sample port with a "blast" of pressurized steam prior to the collection of a broth sample. The steam served to clean and decontaminate the interior surfaces of the pipes to ensure a pure sample for subsequent analysis. However, the contact time between the steam and residual microbial populations in the sample line were not adequate to kill the microorganisms and, therefore, resulted in a dissemination of viable aerosols into the surrounding environment. Work practices are most reliable when used in combination with effective engineering measures such as isolation of the machinery from the operator or automation of the process. For example, microbial exposures during the separation of solids can be reduced by limiting operator interaction with those processes or, if this is not possible, the observance of proper and safe work practices.

Large-scale spills of fermentor tanks can be effectively controlled by concrete dikes constructed around the periphery of the tank. Spilled material is directed to a sump and subsequently pumped to a holding tank for inactivation of the microorganisms. In-line sterilizers may also prove effective prior to the disposal of the biological material. Bulk samples of the inactivated material should be microbiologically examined to validate the efficacy of the sterilization techniques. Spill responders should be equipped with PPE including impervious clothing, gloves, autoclavable boots, and appropriate respirators (e.g., a self-contained breathing apparatus).

SUMMARY

This chapter described controls instituted by the health care industry to combat infectious diseases of concern among patients and HCWs. The primary control strategy has been the implementation of administrative measures that promote aseptic work practices and rapid and effective drug treatments for affected individuals. However, engineering strategies have been shown to be effective supplements in the control of infectious agents. These engineering control measures include providing sharps containers for contaminated needles, and the use of specialized ventilation systems designed for isolation rooms that provide negative pressure to contain patient-generated aerosols. Biotechnology relies on the application of engineering controls similar to those used in the chemical industry. Because many of the unit processes are similar to those employed in chemical industry, it is reasonable to assume that the same engineering control technology is generally applicable, albeit in some cases with modifications. Non-industrial indoor environments present a greater challenge due to the limited understanding of the etiologic agent(s) and the clinical endpoints. However, the recommended approach focuses on controlling environmental conditions (e.g., available moisture) at levels unfavorable for microbiological growth.

Regardless of the industry-specific nature of the microbial exposures and health outcomes, the basic precepts of administrative and engineering control strategies can limit exposures. The complicating issue is that the clinical endpoint can be infectious, toxic, or allergic disease or some combination of these. Knowledge of the causative agent and an understanding of the exposure pathway can focus the choice of the control strategies employed. It is imperative that the control practitioner , whether an industrial hygienist, biosafety specialist, infection control practitioner, or engineer, effectively communicate with other involved professionals (i.e., physicians and epidemiologists) to ensure that all pertinent information is used to design or develop appropriate control efforts.

QUESTIONS

7.1. As a control measure, how can substitution be applied to microbiological hazards to provide for a safer working environment?

7.2. Understanding the differences between the clinical endpoints of disease and the mechanisms of microbial growth and dissemination are critical to the design of effective exposure controls. For a susceptible individual to elicit a response, what three things must occur?

7.3. Describe the relationship between infection, virulence, dose, and host resistance.

7.4. Numeric criteria do not currently exist for the interpretation of environmental measurements of biological agents. Explain the reasons why, covering total culturable or countable bioaerosols, specific culturable or countable bioaerosols other than infectious agents, and infectious agents or assayable biological contaminants.

7.5. What are the three most prevalent life-threatening infectious diseases associated with occupational exposures in the United States?

7.6. In what settings do preventive measures tend to have the greatest efficacy?

7.7. The control of infectious aerosols in the healthcare industry has evolved to include the use of general dilution ventilation to minimize the risk of occupational exposure. Describe the desired movement of airstreams within an isolation environment. Include a discussion of a mixing factor.

7.8. Define bloodborne pathogens and the concept of universal precautions.

7.9. Describe and define Class II BSCs.

7.10. What are the elements required for the proliferation of microorganisms within the indoor environment?

7.11. What are the transport mechanisms by which moisture can enter a building?

7.12. What are the primary goals for remediation?

7.13. Farmer's Lung has been attributed to what microorganisms?

7.14. How do operator work practices effect occupational exposures in the biotechnology industry?

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