Provides resources, information, and tools to advise and assist general workers, health care workers, and management to protect workers in the case of a pandemic.

The Role of the Industrial Hygienist in a Pandemic

2nd edition

Roger D. Lewis and Robert Strode, Senior Editors

A publication of the AIHA Biosafety and Environmental Microbiology Committee

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HEALTHIER WORKPLACES | A HEALTHIER WORLD

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IV. Exposure Assessment: Roger Lewis, Kae Aithinne, Steven Welty, Lisa Brosseau, and Rob Strode

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III. Communicable Hazards with Pandemic Potential – Lisa Brosseau

IV. Exposure Assessment – Roger Lewis

V. Recommended Controls – Donald Weekes

VI. Communication and Coordination – Pablo Sanchez-Soria

VII. Sensors, Data Analytics, Tracking, and Management – John Engel

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Students in Roger Lewis' Saint Louis University Class, Spring, 2021, Contemporary Issues in Global Health, researched and wrote Appendix 5 on unique challenges in industries facing pandemics. The student authors included: Diva Agarwal, Dana Alshekhlee, Deema Alyami, Emma Anderson, Nicole Balmaceda, Andy Banda, Kristin Beduhn, Daniel Blunt, Ed Chau, Nupur Chowdhury, Syreille Clement, Elena Dixon, Dalia Dzekic, Cayla Guarnizo, Kaylee Gutzke, Lacy Hance, Muneeb Hasan, Claire Jenness, Viashali Lingutla, Christa Lolley, Grace Maliborksi, Abigail Maloney, Julieth Masirori, Kathryn Mueller, Paula Naharros, David Olander, Amber Ray, Alayna Roderique, Amela Sijecic, Megan Spasenoski, Rachel Van de Riet, Pooja Velury, and Delaney Walker.

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Dedication

Roger Lewis' contribution to this publication is dedicated to the memory of David A. Sterling, PhD, CIH, ROH, FAIHA, member and officer of the AIHA Publications Committee from 1990–2003.

I. Introduction

A. The Previous Version (2006)

As this document was being finalized in Spring 2021, the Coronavirus Disease 2019 (COVID-19) pandemic had resulted in nearly 600,000 deaths (as of June 10, 2021)[1] in the United States alone and caught many people, including some in government and healthcare, off guard and underprepared. However, authors of the first version of *The Role of the Industrial Hygienist in a Pandemic*, published in 2006 by the American Industrial Hygiene Association's Biosafety and Environmental Microbiology (BEM) Committee, had anticipated that such a pandemic was not only possible but likely.[2–4]

The 2006 document called for social distancing as a first line of protection against pandemic influenza (flu). The document also advocated plans for videoconferencing with employees and avoiding low-ventilation environments. These, along with many other practices recommended in 2006, were implemented 14 years later during the COVID-19 pandemic.

The main concern of the authors of this first version and the healthcare community at large was the potential emergence of an Avian flu, specifically the H5N1 subtype. The fear that H5N1 could develop into a massive pandemic has not yet materialized. The potential for influenza viruses like H5N1, coronaviruses like SARS-CoV-2, and other viruses to mutate and become more pathogenic or develop the ability to infect humans and become efficient in human-to-human transmission will remain a challenge for industrial hygienists well into the future.[5]

B. Goals and Objectives for the Revision

The purpose of this guideline is to enhance and expand the resources, information, and tools the industrial hygienist needs to protect the working public from pandemic risks. The urgency of the ongoing COVID-19 pandemic has brought the AIHA's BEM Committee together again, along with members of other AIHA committees, to update the 2006 version. The committee used the original version as a starting point for this update and then edited existing sections and added new sections to address the current reality of COVID-19. The hope is that this document will prepare industrial hygienists for future pandemics.

C. New Sections Added to Revised Version and Why They Were Added

The 2006 version addressed several areas considered crucial to addressing the industrial hygiene concerns of pandemics.[2] These included the roles and responsibilities of industrial hygienists, a general discussion of biological hazards and how they are transmitted, recommended controls using the traditional hierarchy of controls, and selection of personal protective equipment (PPE), especially as related to respirator use. These sections have been edited and expanded to include a glossary, or "lexicon," for discussing the often confusing and controversial terms for communicable hazards. A section on exposure assessment has been added, which considers total exposure health and exposure assessment of biological and infectious agents. A section on controls explores the concept of source, transmission, and receptors as an alternative for understanding how to address the spread of infectious agents in the workplace. The controls section provides a robust discussion of control banding along with in-depth views of current and future control technologies.

The 2006 guideline reflected the importance of communication and coordination of pandemic challenges with infection control practitioners and emergency responders. Steps for policies and plans for workplace protection and coordination with employees, management, and the public were addressed. These sections have been greatly expanded and recognize, among other things, the importance of culture and language in communication with a diverse workplace. To address these and other "lessons learned," we have added new sections on lessons learned to individual sections in this document.

D. Intended Audience

This document was written to appeal to the career industrial hygienist. We expect industrial hygienists as well as architects, engineers, and safety, healthcare, and public health professionals to benefit from reading or examining relevant sections.

E. How the Document Came Together

Like much of office work in 2020, this document was created via teleconference calls, multiple emails, and phone calls. The work came together quickly during the fall of 2020 and into the first few months of 2021.

F. Lessons Learned

- Guidelines should be updated more frequently as significant new information becomes known, or at least every 5 years.
- The content of the guidelines needs to reflect new science, emerging infectious diseases with pandemic potential, and the changing role of the industrial hygienist in pandemic anticipation, recognition, evaluation, and control.

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II. Roles and Responsibilities

A. The Industrial Hygienist During a Pandemic

The first version of this document described the roles and responsibilities of the industrial hygienist in a pandemic as follows: "to provide advice and recommendations on control measures for the workplace and community ... in coordination with the infection prevention and control specialist, based on the best available information."[1] This was important advice, but the COVID-19 pandemic has, if anything, broadened and perhaps deepened these roles and responsibilities and may inform future pandemic prevention and control efforts of industrial hygienists. From the experiences gathered in 2020–2021, it is evident that industrial hygienists need to *clearly communicate* health and safety guidance. This includes the following information:

- Understanding of aerosol science and respirable pathogens, (i.e., there is no bright line between droplet and airborne transmission of viruses);[2]
- Sources of infection can be controlled through appropriate nose and mouth covers ("face coverings");
- Face coverings differ from actual respirators, which could markedly reduce the need for governmental policies that protect highly exposed and vulnerable workers and those with whom they work;
- Need for innovative research in workplace sampling and control of airborne pathogens;
- Need for research and development in the area of occupational limits for biological agents in the workplace.

This last need is a difficult task but will possibly be surmountable in the future as analytical methods and understanding of infection transmission and infectivity evolve.[3]

It is the industrial hygienist's responsibility to call attention to the impact that a pandemic will have on workers. This is critical at an industrial hygienist's own workplace and, as a broader consideration, for all workers. First responders and essential workers in fields such as healthcare, warehousing, trucking, grocery stores, and food processing allow the rest of us a modicum of normal life during a pandemic and keep the economy moving when businesses shutter.

After reviewing the 2003 severe acute respiratory syndrome (SARS) outbreak in Canada, The Ontario SARS Commission indicated that industrial (occupational) practitioners were essential members of a pandemic response team.[4] The final report of The SARS Commission noted that when occupational hygiene-based approaches were established early to help with planning for, and containing, the outbreak in British Columbia, infections were contained far better than in Ontario where similar approaches were not included. The Ontario response relied heavily on the health sector for practices and controls, whereas the British Columbia response primarily relied on the Workers' Compensation Board input, which included the implementation of typical industrial hygiene practices and controls, and inspections by occupational hygienists.[4]

Industrial hygienists have previous experience with SARS and knowledge and experience in exposure science and other pertinent aspects of worker protection, including protecting the essential workers who were returning to work. Despite this expertise, industrial hygienists were not identified as essential workers by the U.S. Cybersecurity and Infrastructure Security Agency (CISA) during the initial phases of the COVID-19 pandemic. Fortunately, AIHA (with the support of several other Occupational and Environmental Health and Safety organizations) petitioned for essential worker status, and in April 2020, industrial hygienists were listed on the CISA "Essential Critical Infrastructure Workforce" advisory list.[5] It is too soon to know the impact that industrial hygienists had on the COVID-19 response, as the history of the pandemic is still playing out. The "essential" role that industrial hygienists have in protecting workers from any and all health hazards at work, however, is no longer in doubt.

Preparing for a response to a pandemic requires that industrial hygienists have a major role in their organization and its mission (Appendix 1). This will include many considerations, such as developing a business continuity plan (Appendix 2), writing a plan for shutting down and reopening (Appendix 3), including special considerations for workers with pre-existing medical conditions (Appendix 4), and understanding the unique challenges industries face during a pandemic (Appendix 5).

Industrial hygienists need to keep abreast of the latest research that demonstrates how biological agents originate, amplify, and are transmitted to humans using a "One Health" understanding.[6] The globalization of today's world will not end with the COVID-19 pandemic, and industrial hygienists should stand shoulder to shoulder with the public health community at large to prevent and, if necessary, help control the next pandemic.

Finally, the industrial hygienist should remember that in a pandemic, the "perfect should not be the enemy of the good." This can be illustrated by the need to find a metric for increased ventilation to reduce exposure to SARS-CoV-2 beyond simply "more dilution air is better than none." Industrial hygienists can find resources on how to address ventilation for infectious agents in workplaces, schools, and worship service settings.[7–9] Another example of a beneficial but imperfect solution was the emphasis by public health authorities regarding the use of cloth or paper face coverings by the general public. Although face coverings have significant limitations (e.g., they allow for viral transmission and are not the equivalent of a NIOSH-approved respirator), they were considered useful in source reduction and, to a lesser extent, for receptor protection when used by the general public.[10] Based on the COVID-19 experience, there may never be a supply of N-95s sufficient for the entire population to use in a lengthy pandemic. However, the industrial hygienist should emphasize the need for employees to have the proper respirators and other personal protective equipment (PPE), regardless of what public health authorities suggest should be worn by the general public. When respiratory protective equipment (RPE) is needed during a pandemic, the industrial hygienist should clearly communicate the limitations and how it should be worn.

Disagreements between and among academics and practitioners about the most appropriate control technologies to apply in a pandemic should be viewed as a healthy part of scientific debate. That said, industrial hygienists should not wait on the sidelines while other professions and organizations write position documents describing the best methods to protect worker health.

B. Lessons Learned

- Industrial hygienists need to be more visible and participate in health and safety decision making before, during, and after the pandemic.
- Industrial hygienists can play a significant role by working with and educating engineers and public health and healthcare personnel. Industrial hygienists can enhance understanding of the exposures and risks associated with pandemic agents, as well as explain how to control those exposures and risks.
- Although it would have been advantageous to have updated this document prior to the current pandemic, the delay was somewhat fortuitous. During the SARS-CoV-2 pandemic, a wealth of new scientific and other pandemic-related information was generated, which is worth including in this guideline. Additionally, the understanding gained regarding the industrial hygienist's role is valuable to current and future pandemic responses. Nevertheless, the information provided in this document is, by necessity, limited to the information available at the time of editing (May 2021), and new information will likely be available prior to its publication.

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III. Communicable Hazards with Pandemic Potential

A. General Considerations

Although this guideline focuses on communicable biological hazards, the industrial hygienist should recognize that the hazards associated with pandemics are not limited to the organism responsible. For example, there are multiple hazards associated with the use and handling of disinfectants applied on surfaces and equipment. The industrial hygienist should also recognize that the identification of hazards and assessment of risks differ when evaluating biological agents versus chemical and physical agents. Chemical and physical agents are normally evaluated on a quantitative basis (e.g., measured concentrations that are compared to occupational or environmental exposure limits and risk-based criteria). The risks associated with exposure to biological agents are typically determined qualitatively with significant variations based on factors such as host susceptibility, agent pathogenicity, agent stability in the environment, mode of transmission, and the availability of therapeutic interventions (e.g., treatment or vaccinations).

B. Glossary of Definitions and Terms of Art

The language, definitions, and terms associated with communicable diseases may be new to many industrial hygienists. The following glossary is provided to assist the industrial hygienist in communicating effectively with other practitioners they will likely interact with during a pandemic, including infection control, public health, and healthcare personnel. Unfortunately, these practitioners do not always use the same definitions as industrial hygienists. Thus, the terms that follow might not be defined as they would by industrial hygienists or allied professions. The communicable disease and disease transmission-related terms are defined here in relatively simple language in an attempt to provide working definitions that bridge differences across professions. Whereas some of these definitions are paraphrased from standard or medical dictionaries, others represent a combined definition that the authors took from multiple sources, including standard and medical dictionaries and the Centers for Disease Control and Prevention (CDC). Where definitions have not been paraphrased, the source and/or citation has been provided.

1. *Communicable Hazard Definitions*

Communicable refers to the ability of an infectious agent (or biological toxin) to be transmitted from an infected individual to a susceptible host via direct or indirect transmission of the infectious agent or its products. Transmission of communicable agents may also occur via host contact with contaminated fluids (e.g., blood), another animal, a vector, or an inanimate object in the environment (i.e., a fomite).

Direct transmission refers to transmission of an infectious agent that occurs directly between infected and uninfected individuals. This generally refers to direct contact transmission and transmission that occurs via droplets, or aerosols, expelled by the infected person and absorbed, or inhaled, respectively, by the nearby uninfected receptor.

Endemic refers to a disease that is typically found only in a particular people, region, or country [e.g., Coccidioidomycosis (Valley fever)].

Epidemic refers to an increase, often sudden, in the number of cases of a disease above what is normally expected in that population in that area.[1]

Fomite refers to an inanimate material (e.g., countertop and doorknob surfaces, clothing, and other materials that are touched) that can be contaminated by a biological agent such that the agent can be transmitted from the material to the person touching the material.

Host refers to a larger organism (e.g., a person) capable of harboring a smaller organism (e.g., an infectious biological agent) responsible for a disease. Not all hosts harbor or transmit the agent. A **susceptible host** is a person who is not immune to, or has little resistance against, the biological agent responsible for disease and who, if exposed to the organism, is likely to contract an infection.[2]

Indirect transmission refers to transmission of an infectious agent where there is no direct individual-to-individual contact. This generally refers to indirect *contact* transmission (i.e., contact with contaminated inanimate surfaces or third-party contact) and can also refer to aerosols expelled by the infected person and inhaled by an uninfected receptor at a more distant or different location.

Infection refers to the invasion and growth of an organism in the body. An infection may lead to a health or disease outcome if the cells of the body are damaged as a result of the infection.

Infectious refers to an agent that is producing or capable of producing infection.

Mode of Transmission refers to the method that an agent (e.g., infectious agent) may be transmitted from its reservoir to a susceptible host (CDC).[1] Modes of transmission may be further defined as either direct and indirect transmission, with subcategories including direct contact or droplet spread (direct transmission), or airborne, vehicleborne, or vector-spread transmission (indirect transmission).

Outbreak refers to endemic disease that spreads beyond the anticipated number of endemic cases or the presence of an endemic disease discovered in a new location.
An outbreak is similar to an epidemic by definition but is often used for a more limited geographic area.[1]

Pandemic refers to an epidemic that has spread beyond a particular community, population, or region such as over multiple countries or continents. Some definitions require the disease to cross "international borders," whereas other definitions indicate that a pandemic must be a "new disease" (e.g., World Health Organization, 2010).[3]

Pathogenicity is commonly confused with virulence; however, pathogenicity refers to an agent's basic ability to be pathogenic (i.e., the ability to produce disease), whereas virulence describes the degree of an agent's pathogenicity.

Reservoir refers to the habitat in which the agent normally lives, grows, and multiplies (CDC).[2] Reservoirs can include humans, animals, and the environment, with humans being the reservoir for most common infectious diseases.

Transmissibility refers to the relative ability of an organism to be transmitted from the source to the susceptible host. Infectious agents transmitted to susceptible hosts may or may not result in infection or disease.

Vector refers to an organism that carries and transmits an infectious pathogen into another living organism without becoming infected by the pathogen (e.g., a tick carrying bacteria responsible for Lyme disease).

Vehicle refers to substances or objects that can indirectly transmit an infectious agent to a susceptible host. Vehicles can include food, water, biological products (blood), and fomites. A pathogen may or may not multiply in a vehicle.

Virulence refers to the relative ability of an infectious agent (pathogen) to defeat the host's immune or other defense mechanisms, resulting in disease or damage.

2. *Particles and Transmission-Related Terminology*

Aerosols are fine solid or liquid particles that can remain suspended in air. According to Hinds, an aerosol is "a suspension of solid or liquid particles in a gas. Aerosols are usually stable for at least a few seconds and in some cases may last a year or more."[4]

Airborne transmission is a term with varied definitions, depending on the context and the scientific and technical field in which the term is used. Airborne transmission is sometimes referred to as aerosol transmission, with a common distinction being that aerosol transmission occurs over shorter distances than airborne transmission, and airborne transmission requires greater stability of the organism in the environment. Regarding infectious disease transmission, airborne transmission is generally defined as transmission via inhalable particles that remain suspended in the air for extended periods, such that they can be disseminated or travel over long distances while retaining their biological viability (e.g., bacteria) and/or remain capable of replication (i.e., viruses). These particles are generally in the micrometer (e.g., bacterial and fungal spores) or sub-micrometer (e.g., viruses) size ranges.

Contact transmission occurs by transfer from a source to a receptor through contact with the infected individual or a contaminated surface (a.k.a., fomite transmission).

Droplet nuclei are particles derived from larger droplets through desiccation or other forces resulting in a smaller, lighter particle. Droplet nuclei are generally defined as particles that are less than 5 µm in size.[5,6]

Droplets are liquid particles that are large enough that they remain airborne only briefly before settling out due to gravity. Droplets are generally defined as particles in the 5 micron (5 µm) or greater size range.[6–8] Droplet transmission typically occurs when droplets are expelled by an infected person or source at force (sometimes referred to as ballistic droplets) and propelled onto mucous membranes.

Inhalable particulate refers to particles with a mean aerodynamic diameter of 100 µm or less. These are particles that can be breathed into the nose and mouth and deposited into the respiratory tract.

Particles include all types and forms of particulate matter, regardless of dimension (size), mass, and form. Particles can be solid or liquid and may comprise any form, or combination, of matter (e.g., mineral, biological, etc.).

C. Biohazard Risk Categories Developed for Laboratories

The Centers for Disease Control and Prevention (CDC) and National Institutes of Health (NIH) provide biosafety guidance for laboratories handling communicable hazards. The CDC has published *Biosafety in Microbiological and Biomedical Laboratories, 6th Edition*[9] (see https://www.cdc.gov/labs/pdf/SF__19_308133-A_BMBL6_00-BOOK-WEB-final-3.pdf), and the NIH has published *NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules*, Revised April 2019[10] (see https://osp.od.nih.gov/wp-content/uploads/NIH_Guidelines.pdf). The CDC biosafety document focuses on the practice of biosafety and provides guidance for how industrial hygienists can protect themselves and others from infectious agents. The NIH guidelines categorize human disease agents according to a standard risk criterion that can aid the industrial hygienist in understanding how to categorize an infectious agent's risk to themselves and others. These documents provide a framework for the industrial hygienist to understand a biological agent's virulence and transmissibility. Table 3.1 provides a summary of the four Risk Groups (RGs) as defined by NIH.

A review of these categories indicates that most viral agents associated with recent pandemics (e.g., SARS, MERS, etc.) that have acquired human-to-human transmission capability fall into RG3.

As a matter of practicality, the isolation, containment, and administrative controls used routinely in laboratory settings with RG3 and RG4 agents cannot generally be

Table 3.1: NIH Classification of Biohazardous Agents by Risk Group (RG)

Qualitative Grouping	Example Agents with Potential Workplace Significance	Definition
Risk Group 1 (RG1)		Agents that are not associated with disease in healthy adult humans
Risk Group 2 (RG2)	• *Orthomyxoviridae* influenza virus (Seasonal influenza) • *Bordetella pertussis* (whooping cough) • *Coronaviridae* human coronavirus (Seasonal human coronavirus) • *Aspergillus* spp. (Aspergillosis) • *Caliciviridae* norovirus (Norovirus)	Agents that are associated with human disease which is rarely serious and for which preventive or therapeutic interventions are *often* available
Risk Group 3 (RG3)	• *Orthomyxoviridae* influenza virus (pandemic influenza) • *Coronaviridae* SARS, MERS, SARS-CoV-2 • (*Mycobacterium tuberculosis*) Tuberculosis • Human immunodeficiency virus (HIV)	Agents that are associated with serious or lethal human disease for which preventive or therapeutic interventions *may be* available (high individual risk but low community risk)
Risk Group 4 (RG4)	• Ebola virus • Marburg virus • Lassa virus	Agents that are likely to cause serious or lethal human disease for which preventive or therapeutic interventions are *not usually* available (high individual risk and high community risk)

Note: From "Table 1: Biological Agents by Risk Group (RG)," *The Role of the Industrial Hygienist in a Pandemic,* by the AIHA Biosafety and Environmental Microbiology Committee, Fairfax, VA: AIHA, 2006. Adapted with permission.

applied during a pandemic wherein thousands of individuals may be potentially infected. Practical guidelines have been developed by infection prevention and control professionals to minimize transmission and the spread of disease in healthcare facilities. They are listed in Supplement 4 of the Health and Human Services (HHS) "Pandemic Influenza Plan"[11] (see https://www.cdc.gov/flu/pdf/professionals/hhspandemicinfluenzaplan.pdf).

D. Lessons Learned

- Droplet transmission and airborne (aerosol) transmission are not mutually exclusive. Pressing public health needs require the industrial hygienist to consider practical, science-based considerations for their recommended guidance on pandemics.
- Although statutory and other applicable occupational exposure limits (OELs) are generally not available for pandemic agents, Risk Group-based guidance can be used to qualitatively categorize the hazardous nature of the pandemic agent.
- Pandemics may require individuals to work in new or modified environments; however, the same health and safety policy considerations used in the original workplace should apply to these new workspaces.

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IV. Exposure Assessment

A. Occupational and Environmental Assessment for Biological Hazards

Human exposure assessment can be described as a series of steps toward a quantitative or qualitative evaluation of an agent's contact with the human body. This contact can be measured through the intensity, frequency, and duration of the contact. It is also necessary to evaluate the rate at which an agent enters the body (uptake) and the route it takes (i.e., injection, inhalation, dermal, and oral).[1,2] If the agent successfully enters the body, the received amount is considered a dose and the amount actually absorbed is the internal dose.[2] Information for some types of biological agents can be used to assess risk when accompanied by an appropriate exposure assessment strategy. Risk can be assessed using an occupational exposure limit (OEL), or, in the absence of an OEL, hazards and risks for similar agents can be used to formulate other quantitative or qualitative risk assessments.[3]

The emerging pathogens responsible for a pandemic may be ill-defined in terms of the route of exposure and stability and viability in the environment. Samples of whole organism, whole virus, proteins, nucleotides, or other cellular components taken from the air or from surfaces can be used to determine exposure potential for a range of biological agents.[4] These methods can be generally divided into culturable and nonculturable approaches.[4] However, pathogens can also be classified as viable but not culturable, requiring sophisticated sampling and analysis methods for differentiation.[3]

Depending on the biological hazards present, a multitude of sampling and analytical methods may be available to the industrial hygienist. However, the industrial hygienist should be aware of the limitations of these methods and what information they may or may not provide. For example, polymerase chain reaction (PCR) methods could be used to determine the presence of DNA or RNA from a pathogen in air or on surfaces. However, while the genetic markers can identify where the nucleic acid is/was present, they cannot distinguish between a viable and nonviable organism.[3]

An agent that causes a severe illness but requires great numbers of invading organisms to initiate an infection may be considered less pathogenic than another that has a lower infectious dose.[5] Determining how many organisms are needed to invade, overcome host defenses, and infect a living host requires a determination of what is considered the pathogenicity of the organism. Assays have been developed to determine the dose that causes infection in 50% of a population: the ID50 (50% infective dose 50%) or a viral dose (50% tissue culture infective dose, TCID 50%).[5]

Outside of HIV/AIDS, most epidemics and pandemics today arise from airborne transmission of viruses,[6] particularly for respiratory infectious agents. However, major epidemics may spread in other ways, such as the Ebola virus via contact with mucous membranes from contaminated bodily fluids and contaminated surfaces, Cholera through fecal material or contaminated water, and Zika virus via a mosquito-borne vector.[7] These differences in transmission require the industrial hygienist to understand the natural history of these diseases and their sources, modes of transmission, and receptors.

An industrial hygienist should be aware that in the chaos of a rising pandemic, assumptions about the leading modes of transmission may be proven wrong. This was the case for SARS-CoV-2 when well-controlled laboratory studies indicated the long-term stability of the virus on hard, resilient surfaces.[8] However, epidemiological studies have demonstrated that fomite transmission of SARS-CoV-2 was not a critical exposure pathway to human infection.[9,10] Unnecessary and overzealous disinfection of surfaces in the earliest stages of the COVID-19 pandemic resulted in increased occupational hazards to the disinfectants, wasted supplies, and environmental pollution.[10,11] Additionally, overuse of disinfectants may have contributed to increased microbial resistance.[12,13]

Surface sampling can be used to conduct environmental surveillance in a community that surrounds the industrial hygienist's workplaces. This may help determine how widespread the contamination of the infectious agent is in the environment as opposed to the number of infected people in a population. For example, a longitudinal study using swabs for collection of SARS-CoV-2 RNA from community trash cans, ATM touch pads, door handles, and gas station pump handles found that the weekly percentage of positive samples (out of n = 33 unique surfaces per week) best predicted variation in city-level COVID-19 cases with a 7-day lead time.[11]

Modeling exposure with biological agents is a complex process that is limited compared to gases or vapors. Unlike a gas or vapor where ideal gas laws can be used to estimate exposure concentrations in zero ventilation or even well-mixed box models, aerosol particles greater than 0.5 µm (aerodynamic diameter) will not behave like gases (i.e., diffuse). Aerosolization of human pathogens, however, can be modeled while using some of the basic principles of aerosol science. For example, in a room with relatively still air, virus particles in an infected person's exhaled breath will settle out of the air after the particle reaches its terminal velocity. The time for this settling is primarily a function of the aerodynamic diameter of the infectious particle.

At the beginning of the COVID-19 pandemic, some scientists thought that SARS-CoV-2 was only transmitted by large droplets that would not remain airborne after being projected through a sneeze, cough, or clinical intubation procedure. As more studies were conducted, it became evident that SARS-CoV-2 could be transmitted through the airborne route, with one study demonstrating that infectious inhalable particles can be conveyed through exhaled breath up to 4.8 meters from an infected patient in a hospital room that has six air changes per hour.[14] In May 2021, the Centers for Disease Control (CDC) and World Health Organization (WHO) released statements indicating that airborne transmission of SARS-CoV-2 was a significant source of exposure.[15,16]

Occupational exposure limits for biological agents do not currently exist.[3] To date, there are a limited number of validated methods to measure airborne or surface contamination of infectious agents. Occupational infectious disease surveillance data are also limited. However, there is substantial growth in the literature regarding new sampling and analysis methods.[3] Routes of transmission data can also be controversial, and it can take a considerable amount of time to understand these data. Virulence of the infectious agent may also be hard to determine.

B. Modes of Transmission

Epidemics and pandemics are both outbreaks of disease that differ in their geographic coverage. For an epidemic to become a pandemic, multiple factors must be present to enable the pandemic agent access to intercountry or worldwide disease spread. Intra- and intercountry travel of infected individuals, the agent's stability in the environment, and its transmissibility are all key factors that enable pandemic spread. As discussed above, infectious agents capable of causing epidemics and pandemics can be spread in various ways. However, the most common pandemic agents are those that are transmitted from human to human without a vector or through a contaminated media. The following sections discuss factors the industrial hygienist should consider relative to potential assessment and identification of viable modes of transmission.

1. *Precautionary Principle*

In the past, there has been debate among airborne disease scientists, medical professionals, professional engineers, and health and safety practitioners regarding transmission routes and potential risks for these routes to cause infections and disease in humans. The debate regarding the airborne transmission of some infectious agents, particularly viruses and other pathogens, is contentious, especially when easily verified infection routes like droplet and fomite contact play a role in infection transmission. Although not required by OSHA regulations, the use of a precautionary principle is a prudent approach to addressing pandemic disease transmission, especially in the early stages, where an agent or a route of transmission has limited confirmation. The United States Environmental Protection Agency (U.S. EPA) frequently utilizes the precautionary principle as a management philosophy. However, U.S. EPA recognizes that the precautionary principle is not a substitute for quantitative risk assessment because it assumes risk as opposed to quantifying risk.[17] Therefore, application of a precautionary principle as a general policy can be useful in situations where uncertainty exists in what constitutes a risk (e.g., how and at what concentration or dose an agent can cause harm).

For practicing industrial hygienists working in a pandemic, situations will arise where it may not be knowable in the early stages of the pandemic how a pathogen is transmitted, what routes of transmission are verifiable, and what routes cause more or less disease. In these situations, a precautionary principle should be applied to control exposures. Unless there are data to the contrary, all routes of transmission should be considered possible when assessing risks to workers and others who are, or may be potentially, exposed to the pandemic pathogen. The potential for airborne or other, potentially less traditional transmission routes should not be ignored or minimized simply because the suspect pathogen does not yet have a verifiable alternate transmission route(s).

2. *Airborne Transmission*

In an unprecedented 2020 event, 36 scientists from around the world unanimously affirmed that the SARS-CoV-2 virus was airborne.[18] Their letter spurred the WHO to announce that the airborne transmission route of the SARS-CoV-2 virus was plausible. Because both enveloped influenza viruses and coronaviruses have been the sources of worldwide pandemics and super-spreading events, the airborne pathway and its controls are the focus of this section. In May 2021, CDC and WHO agreed with these scientists and released statements indicating that SARS-CoV-2 was transmitted via the inhalation pathway.[15,16]

Historically, many public health and healthcare professionals believed that most virus transmission and exposure occurred by two primary routes: ballistic droplets and surface contact with settled particles containing the pathogen. Consequently, there has been disagreement between various practitioners regarding whether aerosolized pathogens such as influenza and coronaviruses remained airborne. Additionally, there was debate as to whether these aerosols could significantly increase the number of individuals infected by these and other pathogens.

It is well established that humans can create aerosolized pathogens by these exhalation or emission actions, including the following modes:

- Breathing
- Coughing
- Sneezing
- Singing
- Talking
- Vomiting

In a hospital with positive COVID-19 patients, scientists found that: “SARS-CoV-2 levels in exhaled breath could reach 10^5–10^7 copies/m^3 if an average breathing rate of 12 L/min is assumed.”[19] The SARS-CoV-2 emission rate or concentration level in air was estimated based on an assumed amplification efficiency of 75% and a reverse-transcription polymerase chain reaction detection limit of 100 copies/μL. The SARS-CoV-2 particle emission rate is affected by many factors, such as disease stage, patient activity, and possibly age. The investigators found that the SARS-CoV-2 particle emission rate into the air was the highest, up to 105 viruses/min, during the earlier stages of COVID-19. In 2020, the National Academy of Sciences (NAS) hosted the world's leading airborne disease scientists at an Airborne COVID-19 Transmission workshop.[20] Bourouiba noted that "aerosols are transported by exhalation gas flows emitted by a person, which can then be transported over large distances rapidly. As the exhaled cloud that carries them slows down, the background ventilation airflow takes over to disperse the remaining particles in the air in the indoor space."[20] Marr described exposures to smaller inhalable particles that far exceed those to larger droplets and explained that the vast majority of particles observed in human breath are <10 μm.[20] Marr also indicated that "breathing, talking, and singing produce ~100–1,000× more aerosol particles (<100 μm) than droplets (>100 μm)."[20]

At the same NAS workshop, Prather noted that "aerosols represent an important transmission pathway for SARS-CoV-2… transmission in outdoor settings has been much less common than indoors,"[20] which is supported by several lines of evidence:

- "Aerosols can contain infectious SARS-CoV-2, remain suspended in air for hours, and be transported many meters from the source.
- Asymptomatic individuals emit mostly aerosols with sizes mostly less than <10 μm and produce very few droplets.
- Super-spreading events are more readily explained by aerosol transmission.
- Aerosols are more concentrated at close range and can spread and accumulate in a room, leading to both close and long-range exposure.
- Transmission in outdoor settings has been much less common than indoors."[20]

SARS-CoV-2 pathogens can also deposit on surfaces. As discussed in the proceedings, "Resuspension of virus-containing dust or aerosol particles that have settled on the floor, clothing, or other surfaces, as well as aerosolization of fomites, could be another transmission pathway" and "up to half of the aerosols in a room may be attributed to resuspension by walking on floors."[20] Phan et al.'s study supported the resuspension of viruses by showing that persons who visit hospital-bound, influenza-positive patients can be coated with influenza virions that may then be resuspended.[21] Khare and Marr's study showed that forces generated by walking can resuspend particles from the floor and that these particles may include pathogens, such as the influenza virus.[22]

Dental procedures, including teeth cleaning and grinding, can also generate airborne pathogens, with Harrel stating, "aerosols and splatter generated during dental procedures have the potential to spread infection to dental personnel and other people in the dental office."[23] A computational fluid dynamics (CFD) modeling study found that "use of an air cleaner in a dental clinic may be an effective method for reducing dental healthcare workers' (DHCWs') exposure to airborne droplets and aerosol particles."[24]

Medical procedures can also generate airborne pathogens. WHO considers the following hospital aerosol-generating procedures (AGPs) as able to aerosolize pathogens:

- endotracheal intubation
- bronchoscopy
- open suctioning
- manual ventilation before intubation
- tracheotomy
- cardiopulmonary resuscitation[25]

Three well-documented super-spreading events clearly demonstrate how one or more infectious person(s) can perpetrate a widespread airborne coronavirus disease outbreak. This is evidenced by the speed, number of infected persons, fatalities, and distance associated with these events:

1. The 2003 Amoy Gardens SARS outbreak infected 434, caused 42 fatalities, and spread 600 feet.[26,27]
2. The 2003 Prince of Wales Hospital outbreak infected 128, caused 23 fatalities, and spread 50 feet.[28]
3. The 2015 MERS Korean Hospital outbreak infected 166, caused 12 fatalities, and spread throughout the hospital.[29]

A fourth super-spreading event took place early in the SARS-CoV-2 pandemic in 2020:

4. The 2020 Skagit Choir outbreak infected 52 of 61 attendees in one evening, causing 2 fatalities.[30]

In Toronto during the 2003 SARS epidemic, scientists identified airborne SARS RNA in the rooms of symptomatic SARS patients.[31] In 2020, Researchers at Tulane aerosolized and sampled SARS-CoV-2 and reported that the aerosol retained "infectivity and virion integrity for up to 16 hours in respirable-sized aerosols" under laboratory conditions.[8]

Airborne sampling conducted in a Florida Hospital identified airborne SARS-CoV-2 RNA in rooms with positive COVID-19 patients, and investigators were able to culture the SARS-CoV-2 and match the virus to the patients.[14] Nebraska researchers sampled the air and surfaces in the rooms of COVID patents who had come from the Diamond Princess cruise ship outbreak, which scientists later determined was a result of aerosol transmission events.[32] Sampling at the Nebraska Biocontainment Unit and National Quarantine Units identified airborne SARS-CoV-2 RNA in patient rooms, bathrooms, exhaust louver grilles, and the hallways outside patient rooms.[33]

Toilet flushing aerosolization is a proven source of airborne pathogens,[34] and SARS-CoV-2 has been detected in stool samples; however, this study did not attempt to culture SARS-CoV-2 from the samples.[35] One 2021 study found that "Toilets dominate environmental detection of SARS-CoV-2 in a hospital" and "RNA on bathroom surfaces and on the exhaust louver grille.....detection of the virus in the corridor air.....and also on the surfaces of exhaust grilles in the bathrooms suggests the possible existence of airborne virus particles."[36] Wuhan hospitals had multiple surfaces with SARS-CoV-2 RNA detected in the rooms, and air sampling identified viral RNA (19 copies/m^3) in patient toilet rooms.[37]

Scientists aerosolized bacteria via toilet flushing, demonstrating that airborne bacteria could migrate out of a hospital bathroom and into the patient's room and potentially infect individuals in either room.[38] The toilet as a significant airborne exposure route is best understood by a 2014 study by Yu et al.[27] This study documented how, in 2003, SARS virus was aerosolized from bathroom plumbing systems by a SARS-infected individual living in Amoy Gardens apartments in Hong Kong. The best explanation for the outbreak was toilet room fans disseminating the virus up to 600 feet outdoors, infecting people located both downwind and in other buildings.
In what is now understood as the largest known airborne viral disease event ever recorded, as many as 434 people were believed to have been infected by aerosols attributed to a single index patient.[26,27] A 2021 modeling study confirmed that the Amoy Gardens SARS event was in part due to an airborne transmission via the outdoor route. The study noted that "The public health message to increase ventilation by opening windows might not be universally useful, if it increases exposure to airborne viruses. We cannot assume that the outside air is safe."[39] Although this indicates the potential necessity of filtering or otherwise treating outside air, outdoor transmission of pandemic agents is generally much less of a concern than indoor transmission.[39]

Two studies support the fact that heating, ventilation, and air conditioning (HVAC) systems can transport SARS-CoV-2. In Oregon, viral RNA was found in the ductwork, air filters, and penetrating the minimum efficiency reporting value (MERV) 15 air filters.[40] In Sweden, a study found viral RNA in HVAC ducts 180 feet downstream from the rooms of the infected COVID-19 patients.[41] The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) affirms that HVAC systems can transport SARS-CoV-2: "COVID-19 aerosols (small droplets and droplet nuclei) can spread through HVAC systems within a building or vehicle and stand-alone air-conditioning units if the air is recirculated."[42] One classic study found that measles could be spread by the building HVAC system in a school, causing a schoolwide outbreak.[43]

3. *Contact Transmission*

Contact transmission results from contact with pathogens present on, or expelled by, the infected host. Generally, the pathogen must reach the respiratory tract or mucous membrane of the receptor in order to cause an infection. Therefore, controlling contact with an infected individual or the contaminated surface becomes an exercise in eliminating or limiting the interaction between the uninfected individual and the infected host and/or any contaminated surfaces. The following discussion focuses on the contact transmission pathway from the surface to the receptor and the controls that may be used to limit or eliminate this pathway.

Depending on the infectious agent, the surface contact transmission pathway can play a more, or less, significant role in disease transmission. Initially, SARS-CoV-2 was incorrectly considered to have high potential for contact transmission, but this pathway was later determined to be much less likely than inhalation transmission (i.e., droplet or aerosol transmission).[44] The ability of the surface contact transmission pathway to effectively transmit disease will vary with a number of factors, including the organism's viability and accessibility and the number of organisms present on the surface.

In addition to these surface variables, there are several biological factors that affect the contact transmission pathway that are inherent to the infectious agent, such as protective structures (biofilms, coatings, capsules, other host organisms, etc.) and virulence of the infectious agent. Other dynamics also play a role in the development of disease, such as the immune status of the receptor and the dose required to result in disease. All these factors should be addressed when considering the potential for contact transmission to cause disease and when considering the methods of controlling the contact transmission pathway.

Contact transmission is generally easier to control than airborne transmissions because the former relies on agents that are generally fixed at the location and can be eliminated through surface disinfection. However, it has been shown that re-entrainment of settled agents is possible, indicating the potential for both aerosolization and resettling of surface contamination.[20]

The potential importance of the contact transmission pathway for SARS was identified during the SARS-CoV-1 epidemic in 2003. Geller et al.[45] found that coronaviruses are not fragile and have the potential for cross-contamination.

Weber et al.[46] note that inactivation on the hands may limit contact transmission. Mukherjee et al.[47] investigated the in vivo contamination of hands by single individuals with acute influenza infection. This study found that with the amount of virus deposited on hands via realistic coughing and sneezing, no virus could be recovered after five minutes and concluded that "H1N1 does not survive long on naturally contaminated skin."[47] Similarly, Xiao et al.[48] concluded that most of the influenza viruses that are transmitted from the hands of patients to healthcare personnel may be inactivated before the healthcare personnel can subsequently transmit them to inpatients and/or before the inpatients can then touch their own mucous membranes.

In a study by Jones[49] wherein contact, droplet, and airborne transmission of COVID-19 were modeled for healthcare personnel, the results indicated that the mean percent contribution of contact, droplet, and inhalation (i.e., airborne) transmission routes to probability of infection was 6.9%, 32%, and 61%, respectively. However, transmission probability in healthcare may be different from other workplaces.

C. Total Exposure Health Concept in a Pandemic

During the late 1970s and through the 1980s, scientists at the U.S. EPA conducted research in what was called the Total Exposure Assessment Methodology (TEAM).[50] The TEAM approach was based on probabilistic sampling throughout the country relying heavily on personal sampling devices to find out what people were exposed to during daily activities, work, and nonwork. These data were thought to be crucial to inform risk assessment for volatile organic chemicals (VOCs) that were thought to be part of daily life. Data from these early U.S. EPA studies, and many more that were conducted throughout the last 30–50 years, have demonstrated that the measurements and models from outdoor stationary and mobile sources were missing the often-larger exposures (and risks) from VOCs that occur indoors, particularly in homes.[50] The work of U.S. EPA to advocate for total exposure approaches using individualized samplers merged with what industrial hygienists were doing already when evaluating worker exposures.

The concept of Total Exposure Health (TEH) and Total Worker Health® (TWH), supported by the National Institute for Occupational Safety and Health (NIOSH) and multiple professional organizations, views occupational exposures and health, respectively, as conditions that are impacted throughout a worker's day on and off the job. This finding was similar to the U.S. EPA's own studies from an earlier period.[51] TEH and TWH are informed by class-based vulnerabilities.[52] TEH considers exposures that occur throughout the day, and those that impact an individual's health, regardless of where the exposure occurs. TWH focuses on ways to advance workers' health and well-being through programs and practices that integrate protection from work-related safety and health hazards with injury and illness prevention. The TWH concept is illustrated as an inverted pyramid of Eliminate, Substitute, Redesign, Educate, and Encourage (Figure 4.1).[53]

The TEH and TWH paradigms were prescient for industrial hygienists during the COVID-19 pandemic. SARS-CoV-2 infected and spread throughout homes, communities, and workplaces. Homes became workplaces for many through remote work via computers and other technology. At the same time, workplaces became sites of asymptomatic spread, necessitating reconsideration of how a healthy workplace should be designed. Simple symptom screening methods for body temperature and assessment for contact with infected individuals were necessary but not sufficient for quelling outbreaks.

Table 4.1 illustrates how the TWH paradigm was relevant to the COVID-19 pandemic and how it is relevant to planning for a future pandemic.[52] For example, policies of wearing respirators while at work could be an important means of source reductions of viral emission. Recognition that community stay-at-home orders and quarantines can lead to mental exhaustion should be reflected in workplace policies that require isolation during quarantines.[54] In the case of a pandemic, demographics may play a large role in determining risk assessments and controls, especially to vulnerable workers.[55,56] Industrial hygienists are encouraged to study, discuss, and debate which TWH issues ring true for their respective workplaces and workers, now and in planning for future pandemics.

The COVID-19 pandemic mass vaccination campaign, and its monumental public challenges, has made clear the importance of Total Worker Health. Throughout the COVID-19 pandemic and for outbreaks that may occur in the future, the industrial hygienist needs to "be at the table" during discussions of which workers or other populations should receive priority for vaccines (once they are produced). The industrial hygienist can be an expert in understanding configurations that may increase or decrease exposures to a range of agents and stressors, including pandemic agents. Therefore, the industrial hygienist should work with employers, employees and their representatives, local and state health departments, and federal agencies to assist them with understanding who is most at risk for acquiring infection from pathogens that may affect workplaces.

Even as workers start becoming vaccinated, the industrial hygienist should reevaluate the need for some of these controls. Even as some workers become vaccinated, there may still be

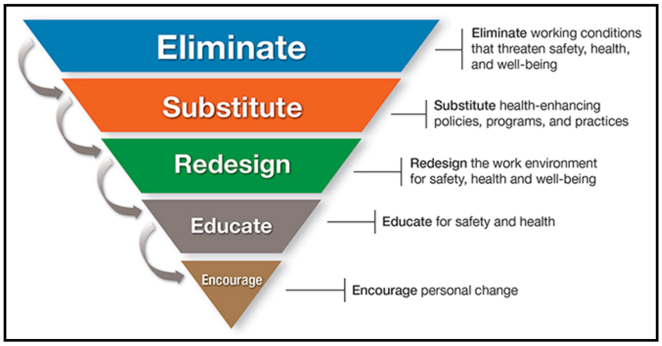

Figure 4.1: Inverted Pyramid on NIOSH Total Worker Health®

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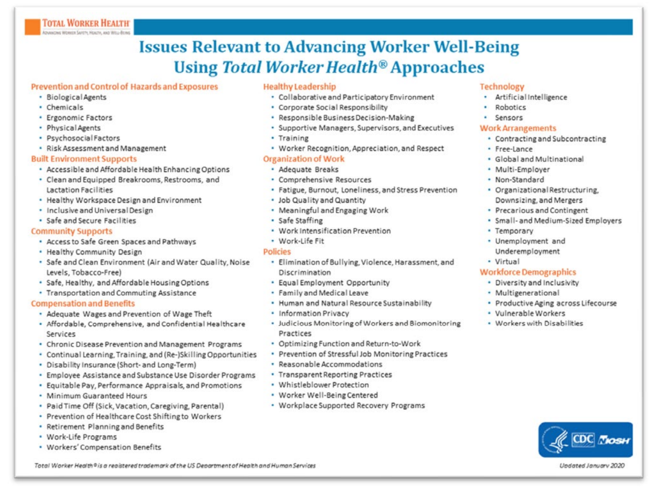

Issues Relevant to Advancing Worker Well-Being Using *Total Worker Health®* Approaches

Prevention and Control of Hazards and Exposures
- Biological Agents
- Chemicals
- Ergonomic Factors
- Physical Agents
- Psychosocial Factors
- Risk Assessment and Management

Built Environment Supports
- Accessible and Affordable Health Enhancing Options
- Clean and Equipped Breakrooms, Restrooms, and Lactation Facilities
- Healthy Workspace Design and Environment
- Inclusive and Universal Design
- Safe and Secure Facilities

Community Supports
- Access to Safe Green Spaces and Pathways
- Healthy Community Design
- Safe and Clean Environment (Air and Water Quality, Noise Levels, Tobacco-Free)
- Safe, Healthy, and Affordable Housing Options
- Transportation and Commuting Assistance

Compensation and Benefits
- Adequate Wages and Prevention of Wage Theft
- Affordable, Comprehensive, and Confidential Healthcare Services
- Chronic Disease Prevention and Management Programs
- Continual Learning, Training, and (Re-)Skilling Opportunities
- Disability Insurance (Short- and Long-Term)
- Employee Assistance and Substance Use Disorder Programs
- Equitable Pay, Performance Appraisals, and Promotions
- Minimum Guaranteed Hours
- Paid Time Off (Sick, Vacation, Caregiving, Parental)
- Prevention of Healthcare Cost Shifting to Workers
- Retirement Planning and Benefits
- Work-Life Programs
- Workers' Compensation Benefits

Healthy Leadership
- Collaborative and Participatory Environment
- Corporate Social Responsibility
- Responsible Business Decision-Making
- Supportive Managers, Supervisors, and Executives
- Training
- Worker Recognition, Appreciation, and Respect

Organization of Work
- Adequate Breaks
- Comprehensive Resources
- Fatigue, Burnout, Loneliness, and Stress Prevention
- Job Quality and Quantity
- Meaningful and Engaging Work
- Safe Staffing
- Work Intensification Prevention
- Work-Life Fit

Policies
- Elimination of Bullying, Violence, Harassment, and Discrimination
- Equal Employment Opportunity
- Family and Medical Leave
- Human and Natural Resource Sustainability
- Information Privacy
- Judicious Monitoring of Workers and Biomonitoring Practices
- Optimizing Function and Return-to-Work
- Prevention of Stressful Job Monitoring Practices
- Reasonable Accommodations
- Transparent Reporting Practices
- Whistleblower Protection
- Worker Well-Being Centered
- Workplace Supported Recovery Programs

Technology
- Artificial Intelligence
- Robotics
- Sensors

Work Arrangements
- Contracting and Subcontracting
- Free-Lance
- Global and Multinational
- Multi-Employer
- Non-Standard
- Organizational Restructuring, Downsizing, and Mergers
- Precarious and Contingent
- Small- and Medium-Sized Employers
- Temporary
- Unemployment and Underemployment
- Virtual

Workforce Demographics
- Diversity and Inclusivity
- Multigenerational
- Productive Aging across Lifecourse
- Vulnerable Workers
- Workers with Disabilities

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Updated January 2020

Table 4.1: Total Worker Health

Note: Reprinted from Centers for Disease Control and Prevention (CDC), 2020 (Reference 52). In the public domain. Source: CDC. This material is available on the agency website for no charge.

a need for controls at the source, transmission pathways, and the receiver/receptor. Many different professionals will be making decisions about worker health and safety, especially after mass vaccination allows many individuals to lower their guard about pathogen transmissibility in the workplace. The industrial hygienist, in conjunction with other members of the healthcare team, must continue to use evidence-based approaches to ensure that pandemic pathogens are not allowed to regain a foothold in society once vaccines are introduced.

D. Occupational Exposure Banding

1. *Definition*

Occupational exposure banding, sometimes also called exposure banding (EB) or hazard banding, is a unique chemical assessment process developed by NIOSH. In this process, chemicals are assigned to concentration-based "bands" (e.g., categories) according to their toxicological effects and adverse health outcomes that result from exposure. Not to be confused with control banding, occupational exposure banding relies on hazard-based data to identify the hazard potential and establish an airborne concentration range for chemicals called an occupational exposure band (OEB). OEBs are not used directly to assign controls.

2. *Known Uses*

The Hierarchy of Occupational Exposure Limits (OELs) utilizes hazard banding strategies at the bottom (base) of the hierarchical pyramid, as they have the least data requirements. These studies are normally limited, and as such, an OEB determines a potential range of exposure levels for a particular chemical. If a chemical has an OEL, the OEL should be used instead of the OEB. However, many chemicals do not have an OEL, especially newer biocidal disinfectants. In the absence of an OEL, and if toxicological data exist, the chemical can be placed into one of five bands (A through E), ranging from highest to lowest concentrations that are expected to protect worker health.[57,58]

3. *Use of Tiers in Assignment of OEBs*

a. *Tier 1: The qualitative tier*

Tier 1 is based on qualitative data harvested from the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). The OEB is assigned based on the GHS hazard codes, and NIOSH has developed a free-for-use e-tool to allow an Industrial Hygiene/Environmental Health and Safety (IH/EHS) worker to complete the assessment in a matter of minutes. The goal of this tier is to provide summary data of the most important health effects and allow for elimination or substitution of the most toxic chemicals. At the time of this publication, the e-tool is located here: https://wwwn.cdc.gov/Niosh-oeb.[59]

b. *Tier 2: The semi-quantitative tier*

Tier 2 uses secondary sources, both qualitative and quantitative, from scientific literature with one of nine toxicological endpoints (e.g., carcinogenicity; reproductive effects and teratogenicity; target organ toxicity from repeated exposure; genotoxicity; respiratory and skin sensitization; acute toxicity; skin irritation and corrosion; eye irritation and corrosion). An assessment conducted for this tier requires some specialized training beyond general IH/EHS training. The resulting OEB assignment is considered more robust due to its reliance on published scientific evidence.

c. *Tier 3: The expert judgment tier*

Tier 3 depends on expert judgment. Because of this requirement, only individuals with a higher level of specialized knowledge, such as a toxicologist or veteran industrial hygienist, can utilize this tier. This OEB assignment requires use of professional judgment in the evaluation of toxicological outcomes (dose-response data) in the assessment, as well as working with primary data drawn from scientific literature.

	A	**B**	**C**	**D**	**E**
Particulate/Dust	>10 mg/m^3	>1.0 – 10 mg/m^3	>0.1 – 1 mg/m^3	>0.01 – 0.1 mg/m^3	≤0.0101 mg/m^3
Gas/Vapor	>100 ppm	>10 – 100 ppm	>1.0 – 10 ppm	>0.1 – 1 ppm	≤0.1 ppm

Note: Reprinted from McKernan LT et al., 2016 (Reference 58) with permission and Lentz TJ et al., 2019 (Reference 57) [public domain]. Source: CDC. This material is available on the agency website for no charge.

4. *Limitations of OEBs*

As with all evidence-based science, the adage of "garbage in = garbage out" can apply to OEBs. The OEB assignment is only as good as the GHS and scientific literature currently published, and the higher tiers (Tiers 2 and 3) require increasingly specialized training in order to result in reliable OEBs. When there is a lack of published toxicological evidence, an OEB should not be attempted. The industrial hygienist should pursue other risk management strategies, including control banding, instead of attempting to derive an OEB.

5. *Potential for Future Use: OEBs for Infectious Agents*

It may be possible in the future to utilize OEBs for classification of infectious diseases into exposure bands as additional knowledge regarding the agents' infectious characteristics and more complete toxicological data are published for these illnesses. Infectious illnesses are reportable conditions under surveillance through Occupational Safety and Health Administration (OSHA), and businesses and industries could, in the future, be required to assess and mitigate potential occupational exposure to concentrations of infectious aerosols that lead to infection.

OELs generally have not been published for biological hazards, as there are complex issues in determining an appropriate OEL. Some of these issues include lack of appropriate sampling methods, lack of human dose-response information, impact of individual susceptibility, mode of transmission, source/reservoir identification, and lack of viable environmental/aerosol concentration data for biological agents. The use of an OEB with a category concentration modification for environmental surface wipe and infectious aerosol concentrations could address some of these issues. This could be accomplished by allowing the use of toxicological studies to place causative agents in more or less stringent categories according to infectious potential, virulence, and particle size distribution. Such banding categories are still in the development stage at the time of this publication.

E. Lessons Learned

- Although there are many similarities between chemical, physical, and biological exposure assessments, pandemic agents differ in that 1) they may be ill-defined in terms of the route of exposure and their stability and viability in the environment; 2) the dose required to cause infection may be consistent, but the health effects elicited may be highly variable depending on receptor factors such as age, gender, comorbidities, etc.; and 3) they lack OELs to guide the industrial hygienist, even when quantitative sampling and analytical methods are available.
- The predominant mode of transmission of a disease may not be what was originally postulated. For most pandemics, airborne transmission should not be disregarded simply because droplet and/or contact transmission are known to occur and/or because the airborne transmission is difficult to verify.
- The concepts of TEH and TWH may be highly applicable during a pandemic because the hazard is likely to be present in the workplace, at home, and in social environments.
- The use of occupational exposure banding for biological hazards is in its developmental stages; however, this process may lead to qualitative and semi-quantitative exposure metrics in the future.

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V. Recommended Controls

A. General Considerations

A key element of controls is understanding the possible approaches to controlling workplace and environmental exposures. Like many other contaminants to which workers are exposed, pandemic organism exposures can be controlled within a framework that borrows from the classic industrial hygiene hierarchy of controls. However, pandemic controls may be better understood through a pathway-based approach similar to noise and radiation controls. To establish this paradigm, Sietsema et al.[1] reframed the traditional industrial hygiene hierarchy of controls in the form of source, pathway, and receptor controls. Although the Sietsema et al. approach focused on aerosol-inhalation transmission, the pathway-based approach can be utilized for other transmission pathways and is the basis for the following sections on pandemic pathogen controls.

The traditional hierarchy of controls approach and the pathway-based control approach have strengths and weaknesses. However, this document utilizes the pathway-based control approach because it is more flexible when considering the significant differences between nonbiological and biological exposures and because of the differences between human responses to toxins versus pathogens.

There are a multitude of variables and uncertainties associated with biological agent exposures, risks, and human responses. For example, mixing air and dispersing contaminants is typically not considered an acceptable control strategy when considering some biological contaminants (e.g., mold spores) and most nonbiological contaminants such as fumes, metals, and other toxic particulate. This is primarily due to the long-term environmental stability of these contaminants, their accumulation on surfaces, and the increased airborne contaminant concentration over time, with or without a continuous source. Conversely, pandemic agents generally have only short-term environmental stability in terms of their ability to remain infectious. Also, the limited viability (e.g., bacteria) or activity (viruses) of the pandemic agent outside the host means that the pandemic agent typically dies or becomes inactive on surfaces. As a result, airborne and surface concentrations quickly become steady state or, more typically, decrease in concentration over short time periods because the source is rarely continuous or consistent.

Relative to the types of controls and their categorization by pathway, some controls are effective across multiple pathways. This crossover can be seen in several of the controls that fit into the traditional industrial hygiene hierarchy. For example, personal protective equipment (PPE) such as respirators and gloves both protect the wearer (receptor control) and can reduce transmission of the pandemic agent (source control). Administrative controls, such as physical distancing and hand hygiene, can be source, pathway, or receptor controls, depending on where in the chain of infection they are applied. The following sections discuss how controls are applicable to sources, pathways, and receptors; how to use control banding to assess exposure and risk; and how to develop control recommendations.

Regardless of the method utilized to address pandemic controls, it is essential that industrial hygienists, public health personnel, and infection control and prevention specialists work collaboratively to devise the best protective scheme for the particular situation. Although there may be many differences in terminology and focus among these practitioners, all practitioners should be working toward the same goal of minimizing the impact of the pandemic on the health and welfare of both workers and the general public.

B. Source Controls

To effectively control disease outbreak, the industrial hygienist or health and safety professional first needs to understand the mode of transmission of that disease. The two primary modes of transmission for most pandemic agents are by particle inhalation and contact (touch) transmission. Source control is the most effective means to mitigate disease spread in the community because it removes or reduces the strength of the disease source.

1. *Source Controls for Particle Inhalation*

a. *Source elimination*

Disease can be controlled by eliminating the source of infectious aerosols through changing the way we work. The best way to stop the particle inhalation is to eliminate in-person contact because that totally removes person-to-person spread of disease. Telecommuting or remote work removes all in-person face-to-face interaction and thus prevents transmission of infectious agents in the air and in the work environment.

However, telework is not the solution for every profession, and many types of work require employees to be present in the workplace, such as those in manufacturing facilities or working with sensitive information requiring a secure environment. For these situations, staggering shift work could be used to reduce the number of workers present in a workplace and, in turn, lower the likelihood of infected workers being present at the workplace.

For the essential worker, where it is not possible or practical to reduce the number of other workers, screening for symptoms and/or testing for the disease can be used as a source control measure. This will lower the likelihood of infected workers as the source in the work environment. However, testing or screening alone might not be enough if work involves interaction with the public. Screening for symptoms, in particular, may not be effective where people are infectious prior to or without developing symptoms (i.e., asymptomatic).

b. *Source minimization*

Minimizing the infectious source is another strategy for source control. Changing the workflow or placement to limit close-contact time and distance might be a viable solution to minimize the source. Moving from a near-field to a far-field exposure (area of a sphere increases with the cube of the linear distance), the viral load will exponentially decay (under ideal conditions). For example, in an open office filled with cubicles, leaving some cubicles open can lower the concentration of the pandemic agent. The parallel example in the manufacturing floor area is the addition of space between workers.

As with chemical generation, the concentration of bioaerosols will build up in a space with little to no air exchange. For agents that do not have a significant airborne pathway, distance may be enough to break the chain, whereas diseases with airborne transmission will require additional controls to minimize spread of the inhalable particulate.

Face coverings and surgical masks may limit, to some degree, the emission of larger droplets from a source. Filter efficiency is generally much less than that of respirators, and fit is not expected or evaluated, making it very unlikely that face coverings or surgical masks will prevent emission of smaller infectious particles. Thus, face coverings and masks should not be counted on to lower the risk of inhalation exposure for anyone spending more than a few minutes in a shared space.

c. *Source isolation*

In some situations, isolating the source makes more sense as a control measure than adding distance between workers. For example, an individual office with a single occupant and a closed door can be isolated from the rest of the office, assuming the room ventilation is also isolated. This can be an effective source control measure because it separates potentially infectious individuals from the rest of the office workers. Setting up physical barriers or enclosures can also be useful for source isolation related to droplet transmission. However, for infectious diseases that can be transmitted through the air, pressurization (typically negative) to direct airflow away from the worker is a necessary supplement as barriers alone are unlikely to be effective against airborne transmission.

2. *Source Controls for Contact Transmission*

The source control strategies for contact transmission are similar to those applicable to aerosol transmission; however, contact-transmitted agents generally are easier to control at the source versus airborne-transmitted agents.

a. *Source elimination*

For disease spread by contract transmission, the safest possible strategy is to ensure that no ill individuals are present in the workplace to spread the infectious agents. Remote work will eliminate the source of infection, but it might not be feasible in many situations. When source elimination is not feasible, source minimization might be the next best strategy for source control.

b. *Source minimization*

PPE such as gloves, respirators, and face shields/goggles are usually used to protect the user (i.e., receptor controls). However, these types of PPE can also be effective as source controls by minimizing the number of infectious agents available for contact by others. It is also important to have proper donning and doffing of PPE. The use of PPE along with proper hand hygiene can help reduce the number of infectious droplets from an infected individual's mucous membrane that can contaminate the surface.[2] Research has shown that practicing proper hand hygiene by either washing hands with soap and water or using alcohol-based hand gel can prevent and/or control infection.[3]

Some publications have indicated that face coverings (frequently called "masks" or "cloth masks") or surgical masks reduce the number of infectious droplets expelled from an individual into the environment.[4–7] However, the published research and reviews are generally focused on laboratory studies and materials testing to determine face covering *efficacy* as a potential source control. Currently, there are no rigorous studies to support the actual *effectiveness* of face coverings in significantly reducing transmission of inhalable SARS-CoV-2 particles, in part because there are no current standards for face covering testing other than the American Society for Testing and Materials (ASTM) F3502–21 *Standard Specification for Barrier Face Coverings*, which is limited to filtration efficiency testing. As stated in Lindsley et al., "Until the factors controlling the performance of source control devices are better understood and better testing methodologies are developed, results from test methods such as filtration efficiency testing, airflow resistance testing, and fit factor measurements should be interpreted cautiously when used to evaluate source control devices for respiratory aerosols."[6]

One study of face covering mandates indicated that policies that mandated wearing face coverings for SARS-CoV-2 had significant reduction in infection in some municipalities. The results highlighted the swiftness of how a face covering ordinance can impact the trajectory of infection rate growth.[8] Other studies indicated that public compliance of moderately protective face coverings could flatten the curve during the COVID-19 pandemic.[9] The results of these studies, both in the laboratory and through ecological study designs, indicate that wearing a face covering can be an important part of source control in a pandemic; however, only respirators have demonstrated effectiveness against respirable particles, i.e., aerodynamic diameters < 5 µm.[9] In light of this uncertainty, engineering controls and NIOSH-approved respirators should be used in place of the less-protective face coverings or surgical masks for employees at work during a pandemic.

c. *Source isolation*

Isolating infected individuals will limit the areas and surfaces that can be contaminated by infectious agents released by the infected individuals. Isolating the contaminated area will limit the potential for uninfected individuals to touch contaminated surfaces and potentially expose themselves to the infectious agents. Isolating the source to a defined area will also help focus the areas requiring cleaning and/or disinfection.

C. Pathway Controls

1. *Pathway Controls to Prevent Infectious Particle Inhalation*

The following sections describe the various controls available for eliminating or reducing inhalable infectious particles. These controls are best considered as options, any of which should be implemented where possible. Additionally, these controls should be implemented with the knowledge that additive, or layered, controls are likely to produce the maximum effectiveness.

a. *Ventilation*

In her 1860 book, Florence Nightingale[10] recognized that fresh outdoor air was an important component in keeping hospital patients safe. She writes, "Keep the air the patient breathes as pure as the external air, without chilling him."[10] Although every engineer or scientist would agree that removing inhalable pathogens from indoors is a good idea, the challenge has been that there is little consensus on just how much outdoor air to introduce along with recirculated air. Many research laboratories use 100% outdoor air (which is expensive to condition) as they vent 100% of their filter-cleaned contaminated air outdoors. This ventilation method is impractical for other settings such as office buildings because of excessive heating and/or cooling costs. It is not generally utilized except in some situations, such as in operating rooms.

Properly designing, utilizing, and maintaining a building's mechanical ventilation system is a vital component of controlling the pathway(s) of inhalable pathogens. At a minimum, it is recommended that all building maintenance staff follow the ASHRAE ventilation Standards 62.1 for buildings and 62.2 for residential spaces.[11,12] Building ventilation system factors that can affect pathogen control include the following:

1. Outdoor air ventilation rate (balanced or pressurized with building exhaust air)
2. Rate of air exchanges per hour (ACH), critically the ACHe (where 'e' is for the efficiency of the air changes)
3. Airflow direction based on the pressurization of the room to adjacent rooms
4. Airflow distribution (airflow from the supply diffusers to the exhaust/return vents)
5. Installing appropriate minimum efficiency reporting value (MERV)-rated filters for the size of the agent or the particles that carry the agent

and making sure that they are sized properly and have no bypass around the filter.

According to the U.S. Centers for Disease Control and Prevention (CDC), industrial hygienists have the following options relative to improving air quality (reducing viral loads) using relatively easy changes to the heating, ventilation, and air conditioning (HVAC):

1. Increase clean supply airflow into occupied spaces when possible.
2. Turn off/disable any demand-controlled ventilation (DCV) controls that reduce air supply based on occupancy or temperature during occupied hours. In homes and buildings where the HVAC fan operation can be controlled at the thermostat, set the fan to the "on" position instead of "auto" because the on position will operate the fan continuously, even when heating or air conditioning is not required.
3. If possible, open outdoor air dampers beyond minimum settings to reduce or eliminate HVAC air recirculation. In mild weather, this will not affect thermal comfort or humidity. However, because of thermal usage, this may increase costs in extreme cold, hot, or humid weather conditions.[13]

Ensuring that airborne pathogens are removed in the most efficient way possible, industrial hygienists can work with professionals who have expertise in air movement within buildings. Appropriate distribution of ventilation (e.g., strategic placement of supply and exhaust vents) can improve room air dilution and lower the buildup and concentration of airborne viral contamination.[14] Additionally, the proper air balancing of supply and exhaust vents can also increase pathogen removal efficiencies.

Many buildings have minimum ventilation rates, and in these "environments, with lower ventilation rates intended primarily to control indoor air quality [i.e., odors] … the likelihood of infected persons sharing air with susceptible occupants is high, posing an infection risk contributing to the spread of the infectious disease."[14]

The 2020 Public Services and Procurement Canada (PSPC) document recommends the following ventilation guidelines for a pandemic such as COVID-19:

- Operate HVAC systems at a higher fraction of outdoor air up to the maximum rate that can be sustained by the building systems. This may require modifications to building systems, such as:
  - Adjusting outdoor air damper position
  - Installing DCV systems (e.g., CO_2 sensors)
  - Adjusting exhaust fans to ensure slightly positive building pressurization.
- Consider operating HVAC systems servicing occupied areas 24 hours a day, 7 days a week to enhance building airflow.[15]

All these recommendations refer primarily to the operation of building ventilation systems that rely on mixing and may or may not be effective at limiting infectious particle concentrations in rooms or spaces depending on the system design and performance. For example, simply increasing the quantity of air may not eliminate areas of poor mixing, dead zones, or short circuiting caused by the improper placement of inlets and outlets in an indoor space.

Regardless of the existing system operations or potential modifications, the facility should consult with a ventilation system engineer to ensure that the system is operating correctly and is well maintained. It is also necessary to ensure that the system can accommodate the added pressure drop resulting from a more efficient filter.

b. *Positively/negatively pressurized rooms*

During a pandemic, if a person is identified as possibly ill with the pandemic disease, they should be isolated in a negatively pressurized room or other area capable of creating a negative pressure barrier (e.g., an enclosure around a bed or the upper part of a bed). In cases where negative pressure cannot be implemented, the facility should consider alternatives such as isolating these individuals near an exhaust vent until they can be removed from the building. The CDC recommends that negatively pressurized rooms ideally should be negative to the hallway or adjoining rooms at a negative pressure greater than 2.5 Pa.[16]

To reduce toilet aerosolization as a contamination source, keep toilet covers closed when flushing and add covers if not present. To minimize aerosol transmission from the toilet area, it is important to ensure that all restroom exhaust vents are sized and working properly, that they are venting to the outdoors, and that the vents are operated continuously. Additionally, the toilet exhaust vent should be located in a way that there is sufficient distance between the exhaust vent and the fresh air intake vent. This will help to prevent re-entrainment into the building of any aerosolized pathogens.[17]

c. *Humidity and temperature*

Maintaining proper indoor humidity is critical for controlling the survivability of airborne pathogens, especially enveloped viruses like influenza and coronavirus. According to Eames et al.:

> The survivability of pathogens in the air depends on many factors, including residence time in the air, the level of moisture (which in part depends on temperature), atmospheric pollutants and UV light ... Both temperature and humidity affect the lipid envelope and protein coat, affecting the period of survival. Temperature and humidity will work together to either destroy the organisms or stabilize them.[18]

Since the 1940s, scientists have performed tests on airborne viruses in different humidity levels. In 1961, Harper found that influenza survived much longer in cooler, drier air—after 23 hr at 7.0–8.0°C, 61% of the aerosolized virus was viable at 23–25% relative humidity (RH) versus 19% viability at 51% RH.[19] In 2012, NIOSH scientists performed a similar test where mannequins "coughed out" flu viruses and different levels of humidity. They found that "total virus collected for 60 minutes retained 70.6–77.3% infectivity at relative humidity ≤23% but only 14.6–22.2% infectivity at relative humidity ≥43%."[20] This study also indicated that "maintaining indoor relative humidity >40% will significantly reduce the infectivity of aerosolized virus."[20]

Yang and Marr state, "Humidity is an important variable in aerosol transmission of IAVs [influenza A viruses] because it both induces droplet size transformation and affects IAV inactivation rates."[21] They also write, "...aerosol transmission route plays a significant role in the spread of influenza in temperate regions" and "the efficiency of this route depends on humidity."[21] Their recommendation is as follows: "Maintaining a high indoor RH [relative humidity] and ventilation rate may help reduce chances of IAV infection."[21]

Studies of SARS-CoV-2 virus have indicated similar results as those of the influenza virus, with Morris et al. stating, "we find SARS-CoV-2 survives longest at low temperatures and extreme relative humidities (RH); median estimated virus half-life is over 24 hours at 10°C and 40% RH, but approximately 1.5 hours at 27°C and 65% RH."[22]

A study by Shaman titled, "Absolute Humidity and Pandemic Versus Epidemic Influenza" found that "Variations of absolute humidity provide a framework that helps to explain the timing of both epidemic and pandemic influenza in temperate regions. As a key modulator of $R_0(t)$ [the measurement associated with the potential transmission or decline of a disease], absolute humidity facilitates influenza transmission should the virus be present and susceptibility within subpopulations be appropriate."[23]

The 2020 ASHRAE position document on Infectious Aerosols supports the relevance of RH in disease transmission, stating, "immunobiologists have now clarified the mechanisms through which ambient RH below 40% impairs mucus membrane barriers and other steps in immune system protection."[24,25]

These findings and recommendations refer to the operation of building ventilation humidification systems.

However, different pandemic agents may be more or less influenced by RH changes, and these differences should be considered when specifying, modifying, or installing humidification equipment or predicting seasonal variations in transmission.

d. *Filtration*

Filtration is one method of reducing the concentration of air contaminants in fresh or recirculating air. Relative to pathway control for inhalable infectious particles, it is assumed that significant pathogen concentrations are not present in fresh air, and the purpose of filtration is to reduce the number of inhalable infectious particles in recirculating air.

A common mistake made when sizing filters is judging a filter's efficiency based on test results of the most penetrating particle size. For example, although high-efficiency particulate air (HEPA) filters are listed as 99.97% efficient at 0.3 µm particle size (the approximate size of the most penetrating particle), it has been demonstrated that HEPA filters can be 99.99% efficient at arresting particles both greater and less than 0.3 µm. Industrial hygienists and engineers who work with air filtration also understand that over time, filters will load with ambient particles, increasing both their resistance and their efficiency.

Because virions will likely be encapsulated in a sputum droplet or droplet nuclei that can range from 0.8 to 2.0 µm, a MERV 13 filter can be highly efficient for removing these aerosols. A 2013 study found that particle capture in the relevant size range peaked, and subsequently plateaued, for filters rated at or above MERV 13, respectively.[26] Based on that study, ASHRAE recommends that MERV 13-rated filters be installed in all HVAC systems that supply air to occupied areas, if feasible. To get the best efficiency from MERV 13 filters, the facility should install gaskets, verify that the filters are tight-fitting in their racks, and verify that there is no air "bypass" around the filters. Similar results have been reported for residential HVAC filters.[27] To ensure proper system operation, the facility should consult with a ventilation system engineer to ensure that the system can accommodate the added pressure drop caused by a MERV 13 or higher-rated filter.[27]

e. *In-room filter-based air cleaners*

In addition to improving system-wide filtration, the ASHRAE Epidemic Task Force recommends that portable in-room HEPA Air Cleaners be used to increase the capture of airborne virions in the local environment, as well as increase the number of ACH.[28] In the ASHRAE guidance titled "In-Room Air Cleaner Guidance for Reducing COVID-19 In Air In Your Space/Room," ASHRAE outlines seven sets of information needed to calculate your in-room unit sizing in the subsection titled "What do I need to know to choose an In-Room air cleaner?"[29] AIHA and the World Health Organization (WHO) also recommend in-room air cleaners with high-efficiency filters.[30,31] The WHO states, "If no other strategy can be adopted, consider using a stand-alone air cleaner with MERV 14/ISO ePM1 70-80% (previously MERV 14/F8) filters. The air cleaner should be positioned in the areas used by people and close to people. Air cleaner capacity should at least cover the gap between the minimum requirement and the measured ventilation rate."[31] This can be verified by comparing the device's clean air delivery rate (CADR) in cubic meters per hour (m^3/hr) with the room ventilation rate.[31] In addition to the CADR, the area of influence and mixing conditions of the space should be considered to ensure maximum efficiency of the portable device."[32,33]

A 2020 study using HEPA in-room air cleaners found that "when classes were conducted with windows and door closed, the aerosol concentration [>3 nm] was reduced by more than 90% within less than 30 min when running the purifiers (air exchange rate 5.5 h–1)."[34] AIHA recommends standalone HEPA filtered air cleaners, and states "Properly selected and installed, standalone single-space HEPA filtration units that are ceiling mounted or portable can effectively reduce infectious aerosol concentrations in a single space room or zone, such as a classroom, elevator, lobby, or office area."[30]

f. *Ultraviolet light*

The American Society of Heating and Air-Conditioning Engineers (ASHRAE), the National Academies of Science, Engineering, and Medicine (NASEM), and the CDC all recommend the use of ultraviolet (UV) lights to inactivate viruses like SARS COVID-19. The CDC also recommends upper-room ultraviolet germicidal irradiation (UVGI) for infection control.[35] The wavelength of UV light typically used [C band at approximately 254 nanometers (nm)] is associated with skin and eye damage, and safety precautions are necessary to protect both occupants and the maintenance personnel. UV lights can be installed inside occupied rooms on the upper section of walls (upper room) and inside HVAC units as a row(s) of UV lights. In both cases, the time the agent is exposed to the UV source and the agent's distance from the UV source together determine in situ effectiveness.

Far-ultraviolet C (UVC) (in the general range of 207–222 nm) may have potential as a safer UVC source and could become a commercially viable adjunct to the 254-nm wavelength.[36] Current studies indicate that exposure to far-UVC has minimal, if any, effect on mammalian cells but can inactivate virus and prokaryotic cells (e.g., bacteria). However, the residence time necessary for 222 nm UVC to kill or inactivate the organism is much longer than required for 254 nm UVC given equivalent power.[37,38]

Ultraviolet systems include lamps using both mercury and light-emitting diodes (LEDs). The lamps vary in power and style, with outputs depending on the type and configuration. Various commercial and noncommercial computer-based programs are available to determine what type and how many UV lights are needed to meet the specified power output in micro-Joules (mJ) needed to inactivate 99% of the airborne pathogen. Determination of appropriate power and residence time to kill or inactivate new pandemic agents will likely require research and testing.

1) <u>Upper-room UV systems</u>
Upper-room UV systems have been shown to be effective in safely inactivating airborne bacteria and viruses within occupied spaces in buildings. NIOSH has an excellent guide to upper-room UV for use in controlling tuberculosis.[39] Two Harvard studies have demonstrated that increased air mixing also increased airborne inactivation effectiveness through the use of ceiling or other fans in conjunction with the upper-room UV system.[40,41] For upper-room systems, the ceiling height, light placement, directionality, penetration of the UV light, stability of materials irradiated during operation, remote shutoff, motion sensors, safety interlocks, and other factors must be considered to ensure proper operation and to protect occupants and maintenance personnel from UV light exposure.

2) <u>In-duct UV systems</u>
The 2021 ASHRAE Epidemic Task Force recommends in-duct UV systems, which provide 1,500 mJ per square centimeter (mJ/cm^2) of UV light irradiance over 24 inches, traveling at 500 feet per minute (or slower), that will inactivate 99% of airborne SARS COVID-19 virions traveling though the irradiated zone.[28] For in-duct applications, a balance between duct size, ventilation flow rate, and residence time in the UV light zone must be achieved to allow the UV light sufficient time for inactivation while also allowing sufficient supply volume for meeting ACH requirements.
For in-duct UV systems, safety considerations apply for operation, including safety interlocks on access doors and UL-approved components. Additionally, the systems must be sealed to prevent any UV light leakage per UL code 1995.

g. *Mixing air using fans*

As noted above, turbulent flow generated with ceiling or other circulating fans can improve the efficiency of ultraviolet germicidal irradiation (UVGI) systems by more efficiently moving pathogens into the path of the UVGI source. However, the use of fans for general room air mixing during a pandemic can be controversial, and directed flow that moves air from an infected individual(s) toward uninfected receptors should be avoided. Generally, displacement ventilation, where air moves away from infected individuals either into a HEPA filtration device or upward toward a ceiling return duct, is the preferred method of ventilating spaces where infected individuals may be present. Mixing the room air uniformly when adequate general dilution ventilation is present may dilute the airborne pathogen in one area of the room. Mixing could also distribute some contaminants farther from the source, potentially exposing receptors farther away. However, uniform mixing of room air may dilute the pathogen sufficiently to prevent the room from reaching the concentration (dose) necessary for infection. Additionally, it may remove pockets of stagnant air where the airborne pathogen could concentrate.

Circulating fans may also be used to increase the amount of air mixing as a supplement to the HVAC system in certain situations. Also, an operable window and/or a fan that can be placed in an operable window location may increase the amount of outdoor air. Alternatively, ceiling exhaust fans can be used to accomplish this goal. When using a window fan, the window fan typically should be placed at the highest level possible, and the air should be directed out the window to avoid airflow being directed horizontally across the room.

h. *Alternative air cleaners*

Prior to and during the COVID-19 pandemic, alternative disinfection technologies have been promoted by their manufacturers. Many of these technologies utilize bipolar ionization (BPI), needlepoint BPI (NPBI), and other electronic/electrostatic devices that charge particles but also create reactive oxygen species (ROS) and ozone. These devices can also generate low molecular weight volatile organic compounds such as formaldehyde. There are known and potential health effects related to these intentional and unintentional products and byproducts. As a result, most public health agencies and national organizations not associated with the manufacturing or sale of these devices have not recommended these devices for COVID-19 disinfection.

Neither the effectiveness in real-world applications nor the long-term safety of BPI equipment have been studied in detail. There are numerous independent studies that have failed to support many of the manufacturers' claims. There are currently no standardized tests to verify BPI claims of virus destruction. As noted by the U.S. Environmental Protection Agency (EPA):

> As typical of newer technologies, the evidence for safety and effectiveness is less documented than for more established ones, such as filtration. Bipolar ionization has the potential to generate ozone and other potentially harmful by-products indoors, unless specific precautions are taken in the product design and maintenance.[42]

An independent Illinois Institute of Technology study tested the efficacy of NPBI systems related to one manufacturer's claims, and it found that the NPBI systems demonstrated poor results.[43-45]

The ASHRAE Epidemic Task Force has the following summary of BPI/Corona Discharge/Needlepoint Ionization and other ion or reactive oxygen cleaners on its website:

- Air cleaners creating reactive ions and/or ROS have become prevalent during the COVID-19 pandemic. New devices that are not mentioned elsewhere in this guidance likely fall into this category.
- High-voltage electrodes create reactive ions (both positive and negative) in the air that may react with airborne bioaerosols like bacteria and viruses. These electronic systems can create mixtures of ROS, ozone, hydroxyl radicals and superoxide anions.
- Systems are reported to range from ineffective to very effective in reducing airborne particulates and acute health symptoms.
- Convincing scientifically rigorous, peer-reviewed studies do not currently exist on these emerging technologies, and manufacturer data should be carefully considered.

- Systems may emit ozone, some at high levels. Manufacturers are likely to have ozone generation test data.[28]

i. Room air evacuation

In certain situations, it may be useful to purge a room's air of infectious agents after a known pathogen source has vacated the room and/or before occupancy of the space by unprotected personnel. In these situations, evacuation (purging) of the contaminated room air can be an effective airborne transmission pathway control. The CDC states that healthcare facilities should allow adequate time for the air handling system to clean 99% of airborne particles from the room's air prior to reoccupancy. In schools, for example, one or more breaks in the morning or afternoon where students leave the room to recreate or study (e.g., a library break) can provide some time to evacuate the air from the room and reduce airborne pathogen loading.[46]

The time period to achieve that safety factor ranges from 46 minutes at 6 ACH to 23 minutes at 12 ACH. It takes fully fifty percent more time for 99.9% removal efficiency. However, these assumptions assume perfect air mixing and the removal of the aerosol-generating person or source (i.e., no continued or continuous source). Caution should be exercised in determining sufficient air clearance times. It is prudent to allow additional time prior to reentry to allow the air to be cleared of the infectious agent(s). Table B.1 of the CDC document is reproduced below as Table 5.1:

Table 5.1: Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency*[47]

ACH § ¶	Time (mins.) required for removal 99% efficiency	Time (mins.) required for removal 99.9% efficiency
2	138	207
4	69	104
6+	46	69
8	35	52
10+	28	41
12+	23	35
15+	18	28
20	14	21
50	6	8

The number of air changes per hour and time and efficiency.
*This table is revised from Table S3-1 in reference 4 [CDC. Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care facilities. *MMWR 43*(No. RR-13): 1-132, 1994] and has been adapted from the formula for the rate of purging airborne contaminants presented in reference 1435 [Rhame FS. Endemic nosocomial filamentous fungal disease: a proposed structure for conceptualizing and studying the environmental hazard. *Infect Control 7* (2 Suppl): 124-125, 1986].
+ Denotes frequently cited ACH for patient-care areas.
§ Values were derived from the formula:

$$t_2 - t_1 = -[\ln (C_2 / C_1) / (Q / V)] \times 60, \text{ with } t_1 = 0$$

where

t_1 = initial timepoint in minutes
t_2 = final timepoint in minutes
C_1 = initial concentration of contaminant
C_2 = final concentration of contaminant
$C_2 / C_1 = 1 -$ (removal efficiency / 100)
Q = air flow rate in cubic feet/hour
V = room volume in cubic feet
Q / V = ACH

¶ Values apply to an empty room with no aerosol-generating source. With a person present and generating aerosol, this table would not apply. Other equations are available that include a constant generating source. However, certain diseases (e.g., infectious tuberculosis) are not likely to be aerosolized at a constant rate. The times given assume perfect mixing of the air within the space (i.e., mixing factor = 1). However, perfect mixing usually does not occur. Removal times will be longer in rooms or areas with imperfect mixing or air stagnation. [Ref 213: (Table 1) American Conference of Governmental Industrial Hygienists (ACGIH). HVAC components, functions and malfunctions (topic 8-4). In: *Industrial Ventilation: a Manual of Recommended Practice, 24th ed.* Cincinnati, OH : ACGIH, Inc., 2001]. Caution should be exercised in using this table in such situations. For booths or other local ventilation enclosures, manufacturers' instructions should be consulted.

Note: Reprinted from Sehulster LM et al., 2004 (Reference 47). In the public domain. Source: CDC. This material is available on the agency website for no charge.

j. Natural ventilation

In situations where operable windows or other sources of fresh air are available via natural ventilation, removal of air contaminants can be achieved through displacement by fresh (outside) air sources. Use of a window fan, placed safely and securely in a window, can be used to exhaust room air to the outdoors and help draw outdoor air into the room via other open windows and doors without generating strong room air currents.[13] The WHO provides calculations that can be used to determine the ACH from natural ventilation based on the following equations, which consider both the size of the opening and the wind-driven infiltration.[48] For example, the ACH and the ventilation rate (VR) for wind-driven natural ventilation through a room with two opposite openings (e.g., a window and a door) can be calculated as follows:

$$\text{ACH} = \frac{0.65 \times \text{wind speed (m/s)} \times \text{smallest opening area (m}^2\text{)} \times 3{,}600 \text{ (s/h)}}{\text{room volume (m}^3\text{)}}$$

$$\text{VR (l/s)} = 0.65 \times \text{wind speed (m/s)} \times \text{smallest opening area (m}^2\text{)} \times 1{,}000 \text{ l/m}^3$$

k. *Pandemic agent transmission*

Figures 5.1, 5.2, and 5.3 illustrate the anticipated distribution of particles emitted from an infected source to other individuals. Note the settling and distance travelled by different-sized particles.[48a]

2. *Contact Transmission Pathway Controls*

Controls for the contact transmission pathway are typically related to elimination via disinfection of surfaces or receptor protection through the use of PPE. Elimination is typically associated with surface cleaning and disinfection (contact transmission control), whereas PPE is typically associated with source and receptor control. As such, the following discussion focuses on elimination and prevention of cross-contamination while receptor pathway controls such as handwashing and PPE are discussed in the Receptor Control section.

a. *Surface disinfection using chemicals*

Surface disinfection includes both disinfection of high-contact surfaces such as countertops, doorknobs, and other common touch surfaces and the disinfection of equipment and instruments that may become contaminated by the infectious agent. Disinfection of surfaces is not the same as the

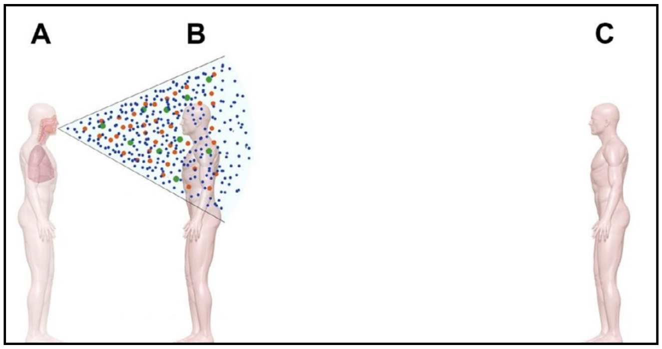

Figure 5.1: When an aerosol is initially emitted (time = 0), the particles are clustered near the source at location A. A person near the source (location B) may receive large-particle spray and inhale particles of all sizes. Note: Figures: Absolute Science Illustration; reprinted with permission of CIDRAP at the University of Minnesota (Brosseau L, 2020; Reference 48a).

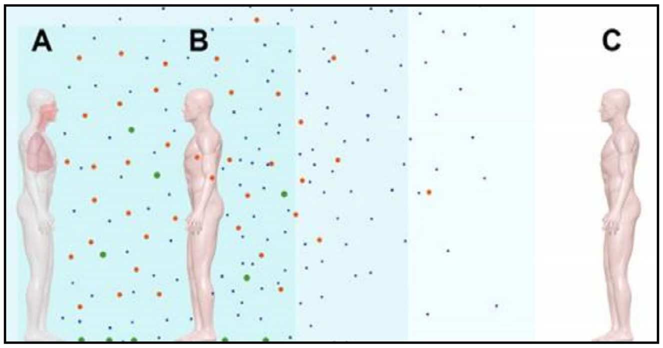

Figure 5.2: After some time (time = 1), the particles begin to disperse and larger particles begin to settle from the air. Person B will continue to inhale particles of all sizes. Note: Figures: Absolute Science Illustration; reprinted with permission of CIDRAP at the University of Minnesota (Brosseau L, 2020; Reference 48a).

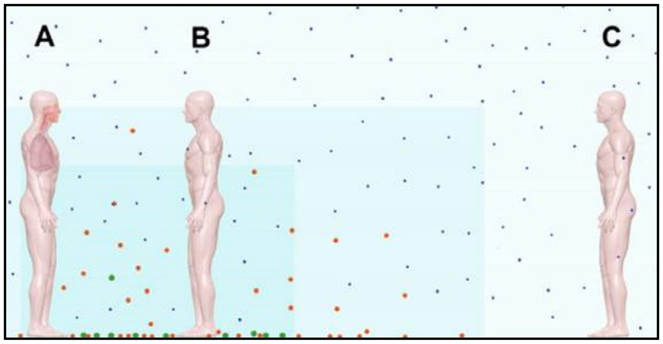

Figure 5.3: After more time (time = 2), the small particles are uniformly dispersed and more of the larger particles have settled from the air. Persons B and C will inhale particles that are generally smaller, have a smaller size range, and are at a lower concentration than at time = 0. Note: Figures: Absolute Science Illustration; reprinted with permission of CIDRAP at the University of Minnesota (Brosseau L, 2020; Reference 48a).

sterilization of these surfaces, and the industrial hygienist should understand the differences between agents that are used for cleaning, sanitizing, disinfecting, sterilizing, and fumigating before specifying use of any antimicrobial agent.

The following discussion focuses on the disinfection of common touch surfaces as opposed to the sterilization of these surfaces. Additionally, surface disinfection can include both touch-based and no-touch disinfection methods. For a more detailed description and understanding of the principles of disinfection versus sterilization, as well as touch-based versus no-touch disinfection methods, please refer to the AIHA *Guidelines for the Selection and Use of Environmental Surface Disinfectants in Healthcare, 2nd edition*.[38]

As noted above, there are a number of factors to take into consideration when using disinfectants. As Rutala and Weber note:

> Survival of pathogens on environmental surfaces is critical to the potential of that surface to act as a reservoir or source of the pathogen. There are many factors that determine the survival of pathogens on inanimate surfaces as well as their transfer to other surfaces. The factors include temperature, relative humidity, topography, porosity, suspending medium, higher inoculate, duration of contact, surface material (e.g., plastic, steel), other microbes, biofilms, product volume to surface area, type of microbe, disinfectant residual, microbial load, and contacting surface (e.g., bare hands or gloves).[49]

Therefore, environmental transmission of coronaviruses via fomites and liquids can be minimized given the proper understanding of the organization and the implementation of appropriate disinfection protocols.

Before specifying any chemical disinfectants, the IH should become familiar with the criteria published by U.S. EPA for antimicrobial pesticides that have been registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The registration specifies the use criteria for each antimicrobial product and pesticide and under what situations the registration applies. The U.S. EPA has developed categories for these registrations that include lists for disinfectants registered for use against specific microbial agents [e.g., List N: Disinfectants for Use Against SARS-CoV-2 and List M: Registered Antimicrobial Products with Label Claims for Avian (Bird) Flu].[38,50]

b. *Surface disinfection using physical methods*

Although most surface disinfection is performed using chemical disinfectants, physical methods are also available. Established physical methods with sufficient testing for efficacy and effectiveness are primarily limited to fixed or portable systems utilizing UVGI in the UVC midrange (254 nm) and Pulse-UV, or near-UV range (405 nm), generated by various lamps or sources.[51,52] Far-UVC (207 to 222 nm), which is generally considered nonhazardous and can likely be applied to surface disinfection, is not widely commercially available at this time.[36,37]

Because of the skin and eye hazards associated with near-UV and midrange UVC, use of these physical disinfectant methods requires that the spaces be unoccupied during their use. Additional concerns include protection from the UV light for maintenance personnel who work on these systems, adequate penetration of the UV light to kill or inactivate the pathogen, and the ability of various materials to withstand the UV irradiation. The protections necessary to address these concerns must include remote shutoff, movement sensors, and/or safety interlocks.

c. *Considerations for use of surface disinfectants*

There are numerous factors to evaluate when considering the use of disinfectants, including both effectiveness in reducing or eliminating the infectious agent and the potential hazards associated with the use of the disinfectant materials and methods. Some examples of these considerations include:

- Using a U.S. EPA-registered disinfectant for the specific application and organism(s), (i.e., liquid or aerosol, touch-based or no-touch) with a label claim for a nonenveloped virus.[38,50,53]
- Using the disinfectant according to the described purpose and instructions, including the proper chemical concentration or power (physical agents), and contact time.
- Avoiding contamination of reusable porous surfaces that cannot be made single use.
- Routine cleaning and disinfection of the PPE doffing area.
- To reduce exposure among staff to potentially contaminated textiles (cloth products) while laundering, discard all sorbent linens.
- Disinfection methods (including UVGI)[54] typically require that the surfaces be cleaned prior to applying the disinfectant material or method.
- Beware of physical disinfection products' (other than UVGI's) claims that do not have sufficient studies demonstrating their effectiveness and potential health effects.

According to Rutala and Weber, "Each disinfectant requires a specific length of time it must remain in contact with a microorganism to achieve complete disinfection. This is known as the kill time (or contact time), and kill times for each microorganism will be listed clearly on the label of EPA-registered disinfectants."[49] EPA-registered disinfectants describe how the disinfectant must be used to achieve the desired goal of killing specified organisms. Failure to follow the instructions may result in increased toxicity to the individuals working with these disinfectants or the microorganisms not being killed or inactivated. This may be demonstrated in the organisms developing a resistance to these disinfectants.

The use of chemical disinfectants for those pathogenic organisms being targeted must be accompanied by professional oversight to ensure that the disinfectant is properly registered for the specific use and being used properly, the dilution is appropriate, the disinfectant is still viable (by noting the expiration date), and the wet contact time is in accordance with that which was stated in the label and product literature. Similarly, the use of physical methods should be overseen by a professional competent to ensure proper use and safety precautions of the physical method. All employees using chemical or physical disinfectants should use the appropriate PPE to protect against direct eye, skin, and mucous membrane contact.

d. *Prevention of re-entrainment*

Re-entrainment or resuspension into the air from settled materials could be considered both a contact transmission pathway and an airborne transmission pathway. However, control of this airborne transmission pathway would largely be determined by thorough surface cleaning. Disinfection may be used to augment surface cleaning. However, disinfection should be unnecessary if adequate and regular surface cleaning is performed. It is important to note that the goal for eliminating the airborne transmission pathway for most pathogens present or settled on surfaces is to minimize the amount of surface particulate that can be resuspended, not to inactivate or kill infectious agents on surfaces.

3. *Airborne and Surface Pathway Control Verification*

Once a pathway control is selected, the industrial hygienist—acting under the constraints of a pandemic—must prioritize which control needs to be verified and how often. For example, if an air handler to an occupied space requires increased air exchange, the industrial hygienist should provide due diligence to see that the facilities services have met the recommended values. There are advantages and disadvantages for use of certain instruments to verify performance of a control during routine situations. This is never truer than during a pandemic, when the ability to take measurements and even get supplies is limited.

The industrial hygienist should begin by conducting an inspection of the HVAC system, along with the facilities supervisor, to ensure that the HVAC dampers are opened to the desired setting and that the filters are in good operating condition. Also, “smoke tube” testing could be used to validate the direction of airflow (from clean to dirty areas).

If a need is established to increase ventilation, this may require system flow and volume measurements, such as use of capture hoods, hot-wire anemometers, or a simple vane anemometer to measure air velocity and volume.[55,56] The industrial hygienist could also recommend use of tracer gases (e.g., sulfur hexafluoride or carbon dioxide) to measure air exchange and outdoor air supply.[57–59] Tracer gases might be needed in discrete locations, especially when it is determined that air mixing in a space is highly variable.[56] Tracer gas measurements using carbon dioxide can be highly variable throughout a day and are closely related to exhaled air during occupancy, provided that there is no source of combustion. At the same time, carbon dioxide measurements, when done with care, can assist with decision making regarding the relative safety of buildings vacated due to pandemic transmission concerns (e.g., reopening schools and businesses) and add an extra layer of protection when occupants are required to wear face coverings.[59] These measurements, however, require a qualified practitioner to interpret their meaning. Examples of some ventilation verification techniques and their advantages and shortcomings are listed in Table 5.2.

Air sampling for some pandemic pathogens, such as coronaviruses, is currently limited to experimental setups and closely controlled situations. Bioaerosol sampling in general has been covered in many books and review articles, including sampling in low-resource countries.[60,61] Impaction, impingement, and filtration are the primary means for collecting airborne bioaerosols, with alternative approaches available.[62] The industrial hygienist can use culturable and nonculturable methods to analyze bioaerosol samples.

The advantages and disadvantages of these analytical approaches have been documented elsewhere.[60–62] The industrial hygienist can find use of polymerase chain reaction (PCR) or adenosine triphosphate (ATP) bioluminescence or some novel method in the open literature, such as use of a method to evaluate airborne agents responsible for inflammatory response in the lung.[63] However, these methods are not conducted in real time, and they often cannot tell us whether we are measuring a viable pathogen. Moreover, these methods require special laboratory arrangements that are not routine to many industrial hygienists in practice. Thus, the usefulness of these methods has not been validated.

Surface sampling to evaluate surface contamination is limited by the same disadvantages as air sampling during a pandemic. Although there are no real-time pandemic pathogen detectors that are routinely available to the industrial hygienist, a grab or integrated air sample could be taken over a known period and analyzed for bacteria, viruses, or other organisms. This is not the case for surface samples, where temporality is almost always a limiting factor. Collection of surface pathogens can make use of filters, swabs, or other wipe approaches.[64–67] Analysis of surface-borne pathogens relies on similar, if not identical, analytical techniques for detecting airborne pathogens after collection. Therefore, they have the same advantages and disadvantages used to analyze an airborne pathogen.

D. Receptor Controls

Receptor controls are the least desirable controls, especially for airborne pandemic agents because they require the use of equipment and methods that rely on an individual’s compliance and/or technique. The equipment utilized includes respiratory protective equipment (RPE) and other personal protective equipment (PPE), as well as proper hygiene, including hand hygiene. However, because source and pathway controls are difficult to implement since the source is usually humans, and it may be difficult or impossible to control at the source or pathway, RPE and other PPE will typically be necessary to control pandemic agent transmission in many situations. When applied, hand hygiene RPE and other PPE selection should address receptor protection as well as comfort, ease of use, and other factors that determine whether and how the receptor controls will be implemented and utilized.

1. Hand Hygiene

Hand hygiene is one of the best techniques to prevent the spread of microorganisms. Throughout the COVID-19 pandemic, cleanliness has been (and

Table 5.2: Ventilation Control Verification Methods: Advantages and Disadvantages

		Ventilation	
Objectives	**Measurements**	**Advantage**	**Disadvantage**
Quantitate airflow	Capture hoods and anemometers	Vane anemometer is easy to use and inexpensive.	Capture hoods and heated anemometers are expensive and may be difficult to source.
Determine air exchange and mixing to evaluate mechanical ventilation	CO_2 concentration (indoor room, outdoors, in duct) CO_2, sulfur hexafluoride for generation and decay measurements	CO_2 measurements are easy to perform. Use of CO_2 and other tracer gases can verify air exchange with reasonable accuracy.	Confounding with occupant carbon dioxide Some tracer gases can be irritating or difficult to source.
Airflow direction	Pressure Differential Manometers Smoke Tubes	Simple to use Simple to use	Not known Irritating to mucous membranes. Non-irritating visual tracers are now available.
Temperature and humidity conditions indoors	Real-time instruments	Can average over time; Readily available	Not known
Filter performance in the field	Particle counting, up and downstream for portable air filters or in duct filters	Can demonstrate whether a filter is functioning as specified Real-time instruments available	May require a specialized setup for portable air filters Instrumentation is expensive

continues to be) an important tool to reduce transmission. Touching an unclean surface or object (including a door handle, sink handle, instrument, or keyboard) can allow microorganisms that may be residing on a surface to migrate to one's unwashed hands, which can then get ingested and/or enter one's body. Additionally, people frequently touch their face (e.g., eyes, nose, or mouth) without realizing it. This provides a means for those organisms to enter one's body. The process of frequently and properly washing one's hands with soap and water is a basic step in removing the organisms.

As of the publication date, the COVID-19 pandemic is especially trying. Handwashing to control this disease continues to be an important component as society strives to stay healthy. The CDC, WHO, and other respected health organizations provide detailed information on hand hygiene techniques when using a soap-detergent with water or an alcohol-based hand sanitizer. It is important to remember that appropriate hand hygiene techniques must be followed: sinks with soap, water, and paper towels must be readily accessible; hand sanitizers must be readily accessible; and, if/when any supplies are depleted, they should be promptly refilled. Currently available sources of information regarding hand hygiene are provided below:

- https://www.cdc.gov/handwashing/index.html
- https://www.cdc.gov/handwashing/when-how-handwashing.html
- https://openwho.org/courses/IPC-HH-en

2. *RPE and PPE*

RPE and PPE selection should follow minimum healthcare guidelines. However, selection of RPE and PPE should always err to the more conservative protection where feasible, and respirators with a higher assigned protection factor (APF) or measured fit factor should be utilized in most cases if given the option. Like all RPE use, consideration must be given to the actual effectiveness of the RPE, which includes user preferences and willingness to properly utilize the PPE. For example, a respirator with a higher APF may not be compatible with the type or length of use required.

When an N95 filtering facepiece respirator (FFR) is acceptable for protecting the wearer, the use of a tight-fitting air-purifying respirator (APR), while likely providing better protection, may not be a better choice if it will not be worn continuously (or properly) due to comfort issues.

RPE and other PPE may be difficult to obtain due to insufficient supplies and supply chain problems during a pandemic. As a result, it may become important to prioritize resources for occupations where there is a greater potential for pandemic agent transmission, such as healthcare and other industries with frontline workers. The need for prioritization will be based on the industrial base's ability to keep up with production and available employer and government stockpiles. Also, during a prolonged pandemic with resources at a premium, employers should consider using durable, reusable PPE designed to be decontaminated. Some reusable RPE with a higher APF, such as powered air-purifying respirators (PAPRs), might be more comfortable for certain uses, both easing the burden of prolonged wear and affording better protection.

Aerosol and droplet transmission will typically require the use of RPE to protect the wearer from pandemic agent transmission when the person being protected is in close proximity to infected individuals. Current industrial hygiene recommendations indicate that, at a minimum, an N95 FFR should be used for protection against pandemic agents when in proximity to potentially infected individuals, although some healthcare recommendations consider surgical masks acceptable forms of protection against droplets. Healthcare personnel working intimately with infected individuals should consider using tight-fitting APRs or PAPRs instead of FFRs due to their higher APF and because they are less likely to allow leakage around the perimeter of the facepiece.

An example of using unapproved RPE was provided during the COVID-19 pandemic. When the recommended RPE was not available (i.e., respirators), surgical masks or cloth coverings were recommended as a preventive measure for both source and receptor control. These alternatives did not provide the same protection as accepted RPE for the wearer. Although face coverings were anticipated to help decrease the number of droplets and aerosols released from the infected person (source control) as well as provide some protection from others (receptor control), they are poor protection from aerosol transmission. The use of face coverings and other PPE that do not meet standard criteria (e.g., NIOSH) should only be considered when appropriate PPE is not available. Although it can be said that any barrier is better than no barrier, inadequate RPE should be considered an unacceptable alternative.

The use of alternatives to accepted RPE and PPE provides a cautionary reminder of the need to stockpile necessary PPE and other equipment that may be required during a pandemic. The shortage of PPE, particularly RPE, during the COVID-19 pandemic was an anticipated pandemic outcome based on prior pandemics and outbreaks; however, a failure to heed these occurrences led to an unacceptable level of PPE and other pandemic-related inventory with which to respond to the pandemic. Additionally, these stockpile deficiencies resulted in such significant shortages of N95 FFRs that methods were developed to decontaminate and reuse the FFRs, which were designed and tested as disposable items; thus, the NIOSH certification of these FFRs was negated. Rather than reprocessing, healthcare organizations could have invested in elastomeric respirators, which would have ensured supplies of FFRs for essential workers in other industries.

The use of PPE such as face shields, and other eye or facial protection, is recommended to minimize mucous membrane (eyes, nose, etc.) exposures from ballistic droplets that can be expelled from infected persons. Face shields and other eye and face protection are not appropriate for preventing the emission of, or protecting the wearer from, inhalable infectious particles. The use of gloves and other skin protection, as well as hand hygiene, is recommended to minimize potential exposure through surface contact transmission.

Programmatic elements of PPE are governed by Occupational Safety and Health Administration (OSHA) 1910.132 for Personal Protective Equipment and OSHA 1910.134 for Respiratory Protection. An important factor to consider when utilizing

PPE is that the workforce must be trained to properly wear the equipment. Workers should be medically cleared for, and properly fitted in, the equipment. Workers should also be trained in the proper maintenance and storage of PPE. A written respiratory protection program administered by a designated person with appropriate expertise, along with periodic evaluation, is also required.

For more information, read 29 CFR 1910.1030 Bloodborne Pathogens[68] or https://www.cdc.gov/niosh/topics/healthcare/infectious.html.[69]

Tables 5.3 and 5.4 show two classic approaches to infection control: Infection Control Measures Used in Healthcare and Industrial Hygiene Control Measures. Because approaches to PPE such as respiratory protection and gloves are different between infection control and industrial hygiene practitioners, the industrial hygienist should work closely with infection and prevention control specialists to ensure the best approach based on the specific situation.

E. Integrating Multiple Modes of Transmission

When determining the appropriate pathway controls, one must consider the potential pathways by which the pathogen can enter the receptor. As described in this and other sections, the absence of a clear demonstration and verification of a particular pathway should not result in ignoring these pathways. Rather, the precautionary principle should be applied, and all pathways should be considered. However, extreme efforts should not be expended addressing pathways with lower potentials to transmit disease, particularly at the expense of pathways that are clearly more significant. In cases where multiple pathways are likely to transmit pathogens and result in disease, a layered approach should be considered that prioritizes efforts and resources based on the likely impact of suspected or known transmission pathways.

Another consideration is how different pathways can affect each other. For example, large (>100 μm) droplets quickly settle and contaminate surfaces. Although aerosols may settle significantly slower than droplets (hours or days/weeks versus seconds), they can also contribute to surface contamination. Thus, controlling the amount of airborne pathogen will also reduce the level of pathogens on surfaces. Similarly, surface pathway controls (e.g., surface cleaning) will reduce the potential for resuspended surface particles that can contribute to the airborne pathway, albeit at relatively low levels, depending on the force applied to them. Consequently, the interplay between these different controls results in an additive reduction in pathogen concentration available for receptor exposure.

From a control standpoint, the layered approach can be seen where one type of control can impact the need for other types of controls.

Table 5.3: Typical Patient-Related Infection Control Measures Used in Healthcare

Scenario	Transmission Mode	Hazard Level	Prescribed Infection Control Measures
Outside the potentially infectious patient's room or containment	Negligible	Minimal	None recommended
Entering the potentially infectious patient's room or containment	Airborne, contact	Low	Surgical mask, vinyl or nitrile gloves, Standard precautions*
Close contact with potentially infectious patient	Airborne, contact droplet spray	Moderate	N95 FFR, PPE (splash protection, vinyl or nitrile gloves, gowns, eye/face cover), standard precautions*
Patient undergoing aerosol-generating medical procedures	Airborne, contact droplet spray	High	N95 FFR (minimum), PPE (as listed in close contact), negative pressure isolation room, and standard precautions*

Note: From "Table 2: Infection Control Measures" in *The Role of the Industrial Hygienist in a Pandemic*, by the AIHA Biosafety and Environmental Microbiology Committee, Fairfax, VA: AIHA, 2006. Adapted with permission. FFR, filtering facepiece respirator; PPE, personal protective equipment. *See https://www.cdc.gov/oralhealth/infectioncontrol/summary-infection-prevention-practices/standard-precautions.html for CDC's Standard Precautions for Infection Prevention. For Standard (Universal) Precautions Guidelines described in the OSHA Bloodborne Pathogens Standard (29 CFR 1910.1030), see www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10051.

Table 5.4: Industrial Hygiene Control Recommendations

Scenario	Minimum Industrial Hygiene PPE Control Measures
Outside the potentially infectious patient's room or containment	None recommended (if the room is under negative pressure; otherwise, N95 or better FFR or N95 or better tight-fitting APR recommended).
Entering the potentially infectious patient's room or containment	No special engineering controls. PPE: N95 or better FFR or N95 or better tight-fitting APR, vinyl or nitrile gloves, standard precautions.*
Close contact with potentially infectious patient	No special Engineering Control needed. PPE: N95 or better tight-fitting APR, (splash protection, vinyl or nitrile gloves, gown, eye and/or face cover, standard precautions.*
Patient undergoing aerosol generating medical procedures†	Negative pressure room. PPE: N95 or better tight-fitting APR, nitrile gloves, protective clothing preferably disposable outer garments or coveralls), an impermeable apron or surgical gown with long cuffed sleeves, impermeable apron, disposable protective shoe covers or boots that can be disinfected, face shield, safety goggles.‡
Workers having the potential to come into close contact with potentially infected live or dead animals, or tissues	No specific engineering control. PPE: N95 or better tight-fitting APR, vinyl or nitrile gloves, gown, eye and face covers, Standard Precautions.*

Note: From "Table 3: Industrial Hygiene Control Measures" in *The Role of the Industrial Hygienist in a Pandemic*, by the AIHA Biosafety and Environmental Microbiology Committee, Fairfax, VA: AIHA, 2006. Adapted with permission. APR, air-purifying respirator; FFR, filtering facepiece respirator; PPE, personal protective equipment.

† Aerosol-Generating Medical Procedures include:

- High-risk procedures include endotracheal intubation and extubation; high-frequency oscillatory ventilation; bag mask ventilation; bronchoscopy and bronchoalveolar lavage; laryngoscopy; positive pressure ventilation (BiPAP and CPAP); autopsy of lung tissue; nasopharyngeal washing, aspirate, and scoping; and sputum induction.
- Other, lower risk procedures include airway suctioning; high-flow oxygen (including single and double O_2 set ups, Optiflow and Airvo); breaking closed ventilation systems intentionally (e.g., open suctioning) or unintentionally (e.g., patient movement); cardiopulmonary resuscitation (CPR); tracheostomy care; chest physiotherapy (manual and mechanical cough assist device [MI-E]); administration of aerosolizing or nebulizing medications; and abscess/wound irrigation (nonrespiratory TB).

*See https://www.cdc.gov/oralhealth/infectioncontrol/summary-infection-prevention-practices/standard-precautions.html for CDC's Standard Precautions for Infection Prevention. For Standard (Universal) Precautions Guidelines described in the OSHA Bloodborne Pathogens Standard (29 CFR 1910.1030), see www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10051.

‡ Safety goggles should offer splash protection, specifically indirect vented or nonvented goggles.

For example, respirators or face coverings meant to protect the wearer as an airborne receptor control can also significantly reduce the potential for the wearer to infect others if the wearer is infected or asymptomatic. The end result is a receptor control that additionally acts as a pathway control, reducing the amount of pathogen expired into the air and settling on surfaces. Surface cleaning and/or disinfection as a contact pathway control can also impact the amount of airborne pathogen present through re-aerosolization. Consequently, the interplay between these different controls results in an additive reduction in pathogen concentration available for receptor exposure.

Although a pathway control approach has been emphasized in this document, we should keep in mind the need to integrate our approach to infectious diseases through implementation of the classical hierarchy of controls.

F. Control Banding for Worker Exposures

1. *Background*

Control banding has been used in workplace exposure assessment for the purposes of identifying appropriate interventions for jobs or tasks where important exposure variables may be missing. In particular, qualitative exposure assessment methods like control banding are useful when toxicity or epidemiological data are limited, sampling or analytic methods are unavailable or technologically infeasible, or quantitative exposure limits are not yet available.

The pharmaceutical industry pioneered the use of control banding as an industrial hygiene exposure assessment tool in the 1980s.[70] Many pharmaceutical materials are bioactive and present significant hazards during manufacturing, but most do not have occupational exposure limits. Control banding was useful in identifying which jobs and tasks involved hazardous exposures, the nature of those hazards, and the most appropriate controls commensurate with the risks. The approach has more recently been applied to nanoparticles, which are complex due to a wide range of hazardous compounds and very small particle size.[71,72]

Control banding is a qualitative decision tool that allows a professional with appropriate expertise, such as industrial hygiene, to identify for a particular job or job task the degree or level of exposure for a particular hazard in combination with some measure of the toxicity of that hazard. Combining these two variables (exposure level and toxicity) allows the professional to identify the appropriate control band for that job or job task, which then provides guidance about the type and nature of controls appropriate to that band. The control band could include very prescriptive guidance on the required controls or could be more general with respect to the types of controls or appropriate levels of the control hierarchy.

Most hazardous biological organisms do not have occupational exposure limits. Infectious organisms with the potential for transmission by respiratory inhalation, such as *Mycobacterium tuberculosis* (MTB), SARS, MERS, influenza, and most recently SARS-CoV-2, are known to transmit person-to-person by aerosol inhalation, but little is known about aerosol exposure levels. In part, this is because we lack sampling and analytical methods that do not adversely impact viability or easily enumerate airborne concentrations. Additionally, we lack the epidemiology that connects exposure to infection and disease outcomes. The only mechanism for ranking toxicity of organisms is a qualitative one developed by National Institutes of Health (NIH) and other bodies for biosafety research purposes, which reflects the availability of preventive or treatment interventions and the likelihood of serious health outcomes. MTB, SARS, MERS, SARS-CoV-2, and novel influenza viruses are all ranked as Risk Group (RG)3 organisms because they lack vaccines or other preventive interventions, have limited treatment options, and can result in serious disease or death. Seasonal influenza is a RG2 organism because there is an annual vaccine that prevents or limits morbidity and mortality in most of the population. Ebola and other similar filo- and arboroviruses are categorized as RG4 because there are no preventive or treatment options and the mortality rate is very high.[73]

2. *Control Banding for Pandemic Organisms*

Exposure to an organism that transmits by aerosol inhalation involves two components: concentration and time. Viral infection that results from intracellular replication is thought to operate on a probabilistic basis, where one virus could elicit infection, but infection that progresses to overcome intra- and extracellular defenses will likely require more than one virus. The median infectious dose, or the number of virions with a 50% probability of bringing about infection in an individual or a population, is generally not known for most organisms but does imply that both the concentration of airborne infectious particles and the duration of exposure to that concentration will play a role in whether an individual's dose is infectious. It should be noted that infection should not be equated with health outcomes or disease, which for respiratory viral organisms will most likely be a function of host characteristics, such as age, gender, and pre-existing health conditions.[74]

With the goal of preserving respirator and other PPE supplies during an infectious disease pandemic, Sietsema et al. proposed a control banding approach for organisms capable of aerosol inhalation transmission that offers a fairly simple method for identifying the level of exposure.[1] The two most important components of aerosol inhalation exposure are the concentration of infectious organisms in the air and the time one is in contact with (inhaling) this concentration. An infectious dose could result from a short contact time with a high concentration or a longer contact time at a lower concentration.

The assumption in this document is that a pandemic is most likely to occur when an organism is capable of rapid person-to-person spread. Organisms capable of exploiting the respiratory system as both a site of infection and a means of dispersion from an infected host to another potential host are among those of greatest concern with respect to an infectious disease pandemic. Inhalation is, by far, a more likely means by which such an organism can reach and commence infection in the respiratory tract, in contrast to large droplets sprayed into the mouth, nose, or eyes or by hand transfer of the organism from a contaminated surface to the mouth, nose, or eyes.

Certainly, these other transmission modes should not be ruled out or ignored for any pandemic organism, and neither should other modes such as exposure to other body fluids or emissions or the contaminated water in which they might travel. Control banding is amenable to any mode of transmission, with the understanding that the nature of exposure and the variables that influence exposure will be different.

a. Exposure considerations

In the case of an organism capable of transmitting by inhalation of small infectious particles that can remain suspended in air for long periods of time (minutes and hours), exposure will be a function of their concentration in air, the host's breathing rate, and the length of time in contact with suspended infectious particles. The control banding model proposed by Sietsema et al.[1] and expanded on by Brosseau et al.[75] for SARS-CoV-2 does not take breathing rate into account but could be easily adjusted to do so.

Sietsema et al. proposed two components of exposure: 1) the likelihood of encountering infectious sources (people) during work and 2) the amount of time spent in contact with those infectious sources.[1] Likelihood is a surrogate for concentration, the assumption being that the more sources one comes into contact with during the workday, the greater the concentration to which one could be exposed.

The model does not consider what infectious sources might be doing. Talking, singing, etc. are known to generate higher concentrations of small particles than breathing.[76,77] As with breathing rate, the "likelihood of exposure" variable could be adjusted to take such "aerosol-generating" activities into account.

Duration of exposure is defined in terms of the number of hours a worker spends in contact with infectious sources. This variable could be easily expressed in terms of percent of shift or any other designation that reflects duration of exposure.

b. Exposure ranking

The control banding model proposed by Sietsema et al. combines the two variables, exposure likelihood and exposure duration, to arrive at an exposure rank (Table 5.5).[1] As noted earlier, this rank could be adjusted by the nature of source activities (e.g., talking or singing, which generate more particles) or by the nature of the receptor's work (e.g., higher work rates that cause higher breathing rates).

c. Toxicity ranking

The other important feature of workplace exposure assessment is understanding the nature of the hazard, or its toxicity. For hazards with exposure limits, such as OSHA Permissible Exposure Limits or ACGIH Threshold Limit

Table 5.5: Determining the Exposure Rank

	Daily Duration		
Likelihood	*D1* *(0-3 hours)*	*D2* *(3-6 hours)*	*D3* *(> 6 hours)*
L1 (Unlikely Exposure)	E1	E1	E1
L2 (Possible Exposure)	E2	E2	E3
L3 (Likely Exposure)	E2	E3	E3

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Values, the toxicity has been addressed in the establishment of that limit by considering animal toxicity and human epidemiological data. For infectious organisms that lack such limits, the best surrogate for toxicity is the Risk Group, which considers both the availability of preventive or treatment options (such as vaccines) and the degree of morbidity and mortality (See Table 1 in Section III. C.). SARS-CoV-2 has been designated a RG3 organism, meaning that it is capable of serious or lethal disease, but there may be some preventive or therapeutic interventions available. MTB, novel influenza, SARS, and MERS are also considered RG3 organisms.

The Risk Group categorization was developed as a method for identifying the types of controls required for conducting research with hazardous organisms. It is recognized, however, that aerosol-generating laboratory procedures, e.g., centrifuging, can trigger higher degrees of protection.

d. *Identifying the control band*

Exposure Rank (E1 to E3) and Risk Rank (R1 to R4) are combined to identify the correct control band, as shown in Table 5.6.

The control band determines which controls should be implemented in which order, following the hierarchy of controls (Table 5.7), as described further.

e. *Hierarchy of controls*

The goal of the Sietsema et al. control banding model was to conserve respiratory protection for frontline healthcare and similar workers by encouraging employers to focus on controls at higher levels of the hierarchy.[1] The investigators reframed the traditional industrial hygiene hierarchy of controls in the form of source, pathway, and receptor controls (Figure 5.4), an approach that has been used when considering hazards such as noise and radiation.

The source, in this case, is any person. In most cases, particularly in the early stages of a pandemic when testing is limited, the infection status of most people will be unknown. Thus, the assumption must be that any person a worker comes into contact with, including coworkers and

Table 5.6: Determining the Correct Control Band

	Risk Rank			
Exposure Rank	*R1*	*R2*	*R3*	*R4*
E1	A	A	A	B
E2	A	B	B	C
E3	A	B	C	C

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Table 5.7: Control Options by Band

Band	Control Options
A	Source – Do these first! Pathway – May be prudent Receptor – Not necessary
B	Source – Do these first! May require multiple options Pathway – Do these next & may require multiple options Receptor – Only if source and pathway controls are not effective
C	Source – Do these first! May require multiple options Pathway – Do these next & may require multiple options Receptor - May be prudent

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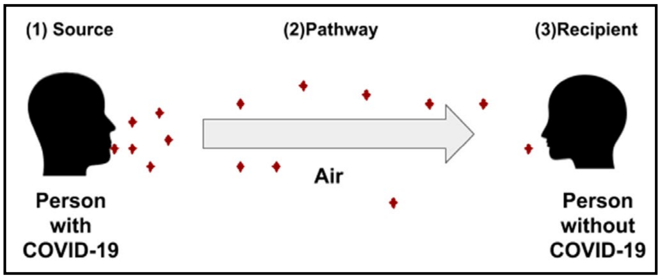

Figure 5.4. Source, Pathway, Receptor. Note: From “Protecting Essential Workers,” Center for Infectious Disease Research and Policy (CIDRAP), 2021. (https://www.cidrap.umn.edu/covid-19/preparedness-and-response/protecting-essential-workers). Figure courtesy of CIDRAP at the University of Minnesota.

members of the public, could be infectious. The likelihood of exposure, as described above, can be framed as the number of close contacts a worker has with other people. With time, the nature of those contacts will be better understood and can be refined. For example, the CDC first defined for SARS-CoV-2 contact tracing purposes a potential "contact" as being within 6 feet of someone suspected or confirmed for 15 minutes. Later in the pandemic, the CDC adjusted this definition to include shorter close contacts that sum to 15 minutes over a 24-hour period.[78] Data from the National Football League's testing program indicate that a single close contact for less than 15 minutes could lead to person-to-person infection.[79]

The pathway involves the movement of the infectious organism from a source to a potential receptor. In the case of aerosol inhalation, this pathway will be determined by the movement of particles in air in a shared space. If the organism remains viable in air for some time, the pathway could extend into adjoining spaces or could be transported to other spaces via the ventilation system. The most important pathway, however, is the one that occurs within a shared space, as particles remain suspended in air and are moved throughout the space by diffusion and air currents.

Controls that protect at the receptor level are at the bottom of the hierarchy and are the least desirable types of controls. These receptor controls usually involve PPE, such as respirators. These are the least desirable because they are often difficult to implement and require cooperation on the part of a worker. PPE can be uncomfortable and difficult to wear for long periods of time; it can also interfere with job tasks or make the job more difficult to perform. All these features make PPE less likely to be worn correctly or continuously, putting the worker at risk of exposure.

Thus, the goal of any control banding model must be to support and encourage the deployment of source and pathway controls ahead and instead of receptor controls. PPE should be reserved and utilized only for those jobs that fall in the control band with the highest risk due to high exposure or significant toxicity.

During a pandemic, it is unlikely that the infectious organism will receive a downgraded Risk Group ranking until vaccines have been developed and demonstrated to be effective at preventing person-to-person transmission. Thus, the goal must be to lower the exposure level by either lowering exposure likelihood or decreasing exposure time.

f. *Control banding example for aerosol transmission mode*

A bus driver could be exposed to many sources, whose infection status will be unknown, over the course of a single shift. Ventilation on many buses travels from the back to the front of the bus, thereby adding to the driver's exposure to infectious particles generated by riders breathing, talking, coughing, etc. The exposure likelihood for this job is high (L3), and the exposure occurs over an entire shift (D3). Thus, the exposure rank is E3 (Table 5.6). If we assume the organism is in RG3, this job falls into Band C (Table 5.7). Band C requires multiple source and pathway controls and may require receptor controls as well. Source controls for this situation could involve limiting the number of people on the bus or limiting the bus driver's contact time by decreasing the time driving a bus (perhaps by rotating into job tasks that do not involve contact with other people for some of the day). If regular and frequent testing were available, only travelers demonstrating a recent negative test could be allowed on the bus. Bus routes could be adjusted to limit the amount of time travelers remain on a bus. If these or similar source controls do not lead to an exposure rank of E1, then pathway controls will be needed. These could include changes in the ventilation design to direct flow upward or downward from passengers to an exhaust rather than from passengers toward the driver. Portable air cleaners could be deployed to collect and clean air at each passenger location, serving as local exhaust ventilation at each seat. The driver's seat could be enclosed in a separately ventilated space, eliminating exposure to passenger emissions altogether. If these options do not lower the driver's exposure rank to E1, then receptor controls may be necessary. The only appropriate PPE to prevent inhalation exposure would be a respirator.

g. *Control banding for other modes of transmission*

As noted earlier, it is usually not possible or prudent to rule out other modes of transmission in the early stages of a pandemic. Any transmission mode is amenable to control banding using the same principles to combine exposure concentration and time for an exposure "rank" and the same hierarchy of controls that progresses from source to pathway to receptor controls.

As an example, an infectious respiratory organism could be transferred by hands or other means to the mucus membranes of a receptor. Exposure will depend on the same variables as those for small particle inhalation: exposure likelihood (how many sources' fluids could a receptor come into contact with) and exposure duration (the entire time over which such contacts could occur).

G. Lessons Learned

- People can be considered a mobile transmission source.
- Use a pathway-based control approach because it is more flexible when considering the significant differences between nonbiological and biological exposures and because of the differences between human responses to toxins versus pathogens.
- It is essential that industrial hygienists, public health personnel, and infection control and prevention specialists work collaboratively to devise the best protective scheme for the particular situation.
- The language or jargon that industrial hygienists and other health and engineering specialists use to communicate transmission of hazardous agents needs to be standardized so that confusion of terms does not hamper the response to a pandemic.
- Although cloth face coverings or surgical face masks have been recommended during the COVID-19 pandemic as a means of source control, these are not an adequate response to the shortage of appropriate NIOSH-approved respirators. Some aerosol and droplet barriers may be better than no barriers, but cloth face coverings and surgical masks allow unacceptably high transmission rates of aerosols.
- The lack of consistent and science-based responses during the COVID-19 pandemic by public health authorities contributed to a loss of trust by the general public and confusion regarding appropriate controls.
- The need for ventilation and other controls and verification of their adequacy needs to be conveyed in a rigorous or even serious manner by public health authorities when there is a potential airborne route of exposure. Failure in this area minimized the protection that appropriate engineering controls could have provided to prevent the inhalation of SARS-CoV-2.
- Pre-pandemic planning is critical to prevent shortages in necessary PPE and hand hygiene supplies.

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VI. Communication and Coordination

A. Communications Planning

Along with obtaining the scientific knowledge needed to prepare effective communication strategies during a pandemic, industrial hygienists, health professionals, and other experts must be prepared to disseminate information in a swift manner, to diverse audiences, and often on a continual basis. In this regard, communication materials should be prepared prior to a pandemic emergency, informing and educating stakeholders about risks and how to protect themselves and those around them.

Because a pandemic emergency can elicit strong emotions for workers and the public in general, it is important that trust and credibility are built and maintained. This can be accomplished by developing messages consistent with those of credible local state and federal authorities, relying on technical experts such as public health professionals, epidemiologists, and industrial hygienists.

Having a multilayered Community Disease Response Plan can right-size a response to a biological hazard. It is not enough to have a plan—the plan must be effectively communicated with your population and practiced for effective execution.

In anticipation of a pandemic, industrial hygienists and public health professionals can play a key role in various communication planning aspects:

- Assess readiness to meet communications needs for a pandemic emergency, including regular review, testing, and updating of communications plans.
- Develop a dissemination or communication plan with employees, other affected individuals, and families including lead spokespersons and links to other communication networks. Ensure language, culture, and reading level appropriateness in communications.
- Anticipate and plan communications to address the potential fear and anxiety of employees, other affected individuals, and families that may result from rumors or misinformation.
- Develop and test communication system (e.g., hotlines, telephone trees, dedicated trustworthy websites, local radio or television) response and actions to employees, other affected individuals, and families.
- Assure the provision of redundant communication systems/channels that allow for the expedited transmission and receipt of information.
- Advise employees and other affected individuals where to find up-to-date, reliable pandemic preparedness information from federal state and local public health sources.
- Disseminate information about pandemic preparedness and response plan to employees. This should include the potential impact of a pandemic on the facility and other building closures and contingency plans.
- Disseminate information from public health sources covering routine infection control (e.g., hand hygiene, coughing/sneezing etiquette, surface cleaning), pandemic disease fundamentals (e.g., signs and symptoms, modes of transmission), personal and family protection and response strategies, and the at-home care of ill employees and their family members.

B. Set Up Policies to Follow During a Pandemic

Establishing roles and responsibilities within an organization during the planning or early response phase of a pandemic is key to streamlining processes and establishing effective communication. Depending on the nature of the pandemic (e.g., route of transmission, virulence, etc.), policies may require input from physicians, industrial hygienists, communications professionals, attorneys, public health and regulatory officials, and others. By having a coordinated process and assigning responsibilities, policy adoption occurs with a higher degree of accountability and can be measured in a tangible manner.

The role of the industrial hygienist in anticipating, recognizing, evaluating, and controlling workplace conditions that may result in worker illnesses is valuable to a significant number of policies directly and indirectly impacting workers. For example, industrial hygienists may:

- Set procedures for activating the organization's response plan when a pandemic emergency is declared by public health authorities.
- Set up policies to prevent the spread of the pandemic disease while business continuity is considered. These may include guidance for respiratory and personal hygiene, administrative controls, and use of personal protective equipment (PPE).
- Set up mandatory, nonpunitive sick-leave policies for employees suspected to be ill, exposed (contact tracing), or who become ill at the worksite.
- Implement policies to allow employees to remain at home until their or their dependents' potential for transmission resolves and they are healthy enough to return to work without impacting other employees (i.e., transmitting pandemic agents). For example, set up policies for nonpenalized leave for personal illness or care for sick family members during a pandemic.
- Follow travel restrictions and recommendations established by local, state, and federal agencies. These may include restrictions to domestic and international sites with outbreaks. Similarly, establish quarantine criteria for those returning from affected areas and/or recovering from infection and monitor symptoms onset.

C. Communicate with and Educate Employees and Affected Persons in the Communities Served

Business and community participation are fundamental to reducing the spread of a pandemic disease. When information is uncertain and anxiety is high, a natural response for people is to attempt to figure out what is going on and what they should do about it. In scenarios where people do not have sufficient information available, they are more likely to misunderstand and misinterpret the limited information available. Industrial hygienists have the education, training, and experience to understand and communicate evolving health and safety procedures and practices to employees and persons in the community. Adequate preparation will strengthen everyone's ability to prevent, prepare for, mitigate, respond to, and recover from a pandemic.

The industrial hygienist can communicate information about the infectious disease, including symptoms, transmission routes, ways to protect oneself, and how to care for ill family members. Furthermore, the industrial hygienist can address rumors, misinformation, fear, and anxiety. Effective and consistent communication during a pandemic is crucial to maintaining trust and restoring morale and confidence.

Advice and recommendations can be distributed physically, electronically, and communicated verbally during live and/or virtual meetings and events. To enable timely communication of critical information, the industrial hygienist should validate that emergency notification systems are in place and tested on a routine basis. Communication materials should also be prepared and tested to ensure their acceptance and understanding prior to a pandemic emergency. The ability to effectively communicate virtually became extremely important during the COVID-19 pandemic.

Here are ways the industrial hygienist can communicate with and educate employees and persons in the communities served:

- Distribute materials with basic information about pandemic pathogens: signs and symptoms, how the disease is spread, ways to protect individuals and their families (e.g., hand hygiene, cough etiquette, use of face coverings, quarantine and isolation protocols), family preparedness plans, how to care for ill persons at home, and when to seek emergency medical attention.
- When appropriate, include basic information about pandemic agents in public meetings (e.g., classes, trainings, small group meetings and announcements).
- Monitor federal, state, and local public health communications about pandemic regulations, guidance, travel restrictions, and recommendations and ensure that employees and other affected individuals have access to that information. This information is likely to rapidly evolve over the course of the pandemic.
- Develop tools to communicate with employees about pandemic status and the organization's actions. This might include websites, flyers, local newspaper announcements, prerecorded widely distributed phone messages or webinars, etc.
- Consider the organization's unique contribution to addressing rumors, misinformation, fear, and anxiety.
- Share information about the pandemic preparedness and response plan with employees and affected persons in the communities served.
- Ensure that what you communicate is appropriate for the cultures, languages, and reading levels of employees and persons in the communities served.

D. Coordinate with External Organizations and Public Assistance/Help Community

Pandemics require a high degree of coordination between public, private governmental, health, and other stakeholders to provide an adequate and comprehensive response to a pandemic event. The industrial hygienist should work with local and/or state public health agencies, healthcare facilities, and insurers and regulatory authorities to understand their response plans and what they can provide. Share preparedness and response plan details and what the organization is able to contribute and take part in the organization's planning. The organization should coordinate with local agencies on any direct efforts to support communities and not impede any public assistance efforts that are under way. Also, keep in mind that a pandemic may constrain or restrict the availability of public infrastructure, especially as other companies are impacted by the same issue. Aspects that may support effective coordination across organizations may include:

- Understanding the roles of federal, state, and local public health agencies and emergency responders and what to expect and what not to expect from each in the event of a pandemic.
- Appointing a point of contact to maximize communication between your organization and state and local public health systems.
- Refraining from distributing materials that conflict with guidance of federal, state, and local public health agencies, as this can lead to confusion and fear among employees.
- Coordinating with emergency responders and local healthcare facilities to improve availability of medical advice and timely/urgent healthcare services for employees and persons in the communities served.
- Sharing lessons learned from developing your preparedness and response plan with other companies to improve community response efforts.
- Working together with community organizations in the local area and through networks (e.g., denominations, associations, etc.) to help communities prepare for pandemic.
- Understanding the concept and determination of essential workers and whether your employees are included.
- Being cognizant of critical supplies for pandemic response (e.g., PPE) and keeping a sufficient reserve for your business needs while sharing, if possible, with healthcare and other frontline employees with potentially greater needs.

E. Communication/Coordination with Workforce

It is likely that the industrial hygienist may take a lead role in planning and implementing the communication and business continuity plan for your workplace. If pandemic planning considerations have not been incorporated into existing business continuity and disaster recovery strategies, do not wait to begin planning pandemic strategies and actions. It is important to discuss plans and policies for business continuity with employees and union representatives to ensure that feedback from those present in the workplace can be considered.[1] Although the planning may be similar to other emergency and disaster planning, there are key differences in the effect of a pandemic. Some of these differences include:

Widespread Impact: Because the impact of a pandemic may be nationwide, there may be little outside assistance available to your business due to a shortage of available resources. Perform an assessment of processes, functions, supply chain, etc. with critical third-party dependencies to understand key risks.

Duration and Notice: A pandemic may not be a short, limited event like a physical disaster that would lead immediately to a recovery phase. Also, it is likely that there will be some advance warning, although this could be very short.

Primary Effect on Staffing: Unlike natural disasters, where business disruption is largely hardware or utility related, the disruption to business services during a pandemic is anticipated to be human resource and/or supply chain related.

Planning for employee absences can be difficult due to uncertainty in the numbers of employees who will become sick, incapacitated, or otherwise unable or unwilling to come to work. Additionally, the workforce may or may not be considered essential, so staffing levels may fluctuate dramatically. A general recommendation would be to plan for more than 50 percent absences for at least two weeks at the height of a severe pandemic and lower levels at the beginning and end of the pandemic. Planners should consider that employee absences can be expected for many reasons, including illness, caring for ill family members, school closures, or simply because people may feel safer at home.

F. Plan for the Impact of a Pandemic on Staff

Along with implementation of policies that increase flexibility for workers, organizations need to consider potential indirect impacts of a pandemic on business continuity, such as public transportation closures, supply chain disruptions, etc. Preparedness plans should incorporate an assessment of these types of impacts on staff and should consider contingencies. Furthermore, evaluations of the effect of a pandemic on staff should consider industry-specific and department-specific vulnerabilities. For example, whereas a manufacturing facility that produces goods may not be able to adopt remote work policies for workers conducting manual labor on a production line, workers in the human resources, accounting, and marketing departments may be able to work remotely. The ability to accommodate and utilize at-home or remote workers may be critical in determining whether a business can successfully navigate a pandemic.

Throughout this process, it is critical that the industrial hygienist evaluates exposure risks across the board and considers job tasks, frequency of close interactions, ventilation, cleaning and disinfection procedures, etc. to help management make decisions that best fit the organization. The industrial hygienist should consider the following:

- Plan for extended staff absences (weeks to months) during a pandemic due to personal and/or family illnesses, quarantines, school closures, etc. Staff may include full-time, part-time, and volunteer personnel, as well as contract workers. If additional personnel are brought in, the industrial hygienist should ensure that onboarding information educates employees on workplace hazards as well as on minimizing risk of exposure to pandemic diseases in the workplace.
- Work with local health authorities to encourage vaccination (if available) for employees and communities served.
- Evaluate access to mental health and social services during a pandemic for staff members and persons in the communities served; improve access to these services as needed.
- Identify persons with special needs (e.g., elderly, disabled, limited English speakers). Include their needs in response and preparedness plans and establish relationships with them in advance to foster trust during a crisis.
- Allocate resources while considering services that are most needed during the emergency (e.g., mental health, social services).

G. Message Mapping Where Language Can Be a Barrier

One of the most important keys to successful communication in high-concern situations such as a pandemic is an organization's ability to establish, maintain, and increase trust and credibility with employees, regulatory agencies, the media, and the public. Message mapping follows principles of communication that include a) organizing information in an easily understood and accessible way; b) expressing the current viewpoint of an organization on important issues, questions, or concerns; and c) promoting open dialogue both inside and outside the organization.

During controversial, stressful, or emotionally charged issues, accurate and easily understood messages are essential. Message maps are crucial to ensuring that an organization has a central repository of consistent messages, as this allows for the organization to speak with one voice. The industrial hygienist must consider the information available and carve out a roadmap of organized responses to anticipated questions. Preparing such messages requires identifying stakeholders as well as questions and/or concerns they may have. Anticipation of questions allows for identification of common underlying concerns. Once common patterns have been identified, key messages can be drafted to address general and specific questions. The industrial hygienist may play an important role in this process by brainstorming with communicators, key members within organizations, policymakers, and subject matter experts to help develop key messages that can be presented as one voice with a concise narrative. This approach to communication also allows for accurate messaging for diverse audiences to achieve maximum communication effectiveness.

Psychological and language barriers can interfere with cooperation and response from the public. Uncertainty, anxiety, fear, denial, hopelessness, and even panic can result in irrational behaviors during a pandemic crisis, impacting the public's ability to absorb information and act differently from nonemergency situations. Under these conditions, a person's ability to process information may be reduced by over 80 percent.[2] Therefore, messages should be simple (i.e., use plain language) and brief. If possible, messages should also include graphics and other pictorial material to clarify information.

H. Communication with the Public

Educating the public about risks and the risk assessment process behind guidelines and recommendations is important. As the public must be encouraged to change behaviors that increase risk of infection or disease transmission, the industrial hygienist should provide guidance on changes that help reduce risk.

When communicating with the public during a pandemic, the industrial hygienist must acknowledge people's concerns and respond to opinions, emotions, and reactions. Although message mapping is a useful tool for anticipating questions and concerns, professionals who directly interact with the public must recognize that risk communication is a two-way street. For example, instead of attempting to persuade individuals or a community group to take certain action or change certain behaviors, asking questions from the audience allows them to persuade themselves, forces the process to slow down, and lets everyone stop and think before replying.

During an outbreak of an infectious disease, emergency responders may be faced with the challenge of restricting civil rights, such as a requirement for individuals to quarantine. Communication with the public in this scenario is critical, as a population that understands the value of quarantining is more likely to uphold the quarantine requirements and support this decision.[3] With this in mind, the industrial hygienist should recognize that communication in a high-stress situation such as a pandemic may not always reduce conflict. Although effective risk communication may not improve the situation (i.e., unwilling communities requested to quarantine may never be convinced that this risk management decision is appropriate), bad or no risk communication will certainly make it worse.[4] Engaging through all available channels of communication, including social media channels, is an important aspect of ensuring that a consistent message is communicated with the broader public. Following recent disease outbreaks and disasters, the CDC concluded that social media for public health messaging was an effective strategy because it was able to reach diverse audiences, establishing interactive and ongoing community engagement, facilitating public control and empowerment, and increasing the likely impact and broadening the transmission of urgent public health communications.[5,6]

I. Medical and Infection and Prevention Control Specialists

1. *Pandemic Committee Membership*

In many parts of industry, the Environmental Health and Safety (EHS) Department and the Occupational Health Department report to different management. Communications between these two functions are critical to workplace safety and health. This is especially important in the healthcare field during a pandemic.

Most hospital and clinical organizations have a multidisciplinary pandemic planning committee as part of their business continuity plan. Industrial hygienists need to participate on these committees. It is important that industrial hygienists advocate for their discipline so that information on exposure and risk assessment, sampling, ventilation, and PPE can be conveyed to decision makers prior to and during a pandemic.

2. *Mode of Transmission Review*

The modes of transmission in a pandemic are often described by public health practitioners, but COVID-19 has illustrated the need for more input by aerosol scientists and industrial hygienists to advise on how this transmission may occur. Once the modes of transmission are known, the industrial hygienist can work with the infection control specialist to plan the strategies to assess these potential transmission modes and provide control strategies to protect workers, visitors, and patients alike.

3. *Expertise in Engineering Control and PPE Selection*

The industrial hygienist, in collaboration with the occupational health team and facilities engineers, will make recommendations about engineering controls. Examples include physical isolation, local and general ventilation, pressurization and direction of airflow, accepted air cleaning devices (filters, UVC, etc.), and proper PPE, as applicable and appropriate.

4. *Review the Toxicological Risk of Using Disinfectants*

The industrial hygienist has a critical role in the selection of disinfectants. The AIHA *Guidelines for the Selection and Use of Environmental Surface Disinfectants in Healthcare, 2nd edition* is an excellent resource for assisting the industrial hygienist with proper disinfectants and uses.[7] The EPA also maintains a list of approved disinfectants that can be used for pathogenic agents such as SARS-CoV-2 (https://www.epa.gov/coronavirus/about-list-n-disinfectants-coronavirus-covid-19-0).[8]

J. Emergency Responders/Emergency Preparedness, Personnel, and Public Health Agencies

Industrial hygienists can serve a crucial and essential role in the emergency communications network of organizations that are involved in planning for, or responding to, the widespread outbreak of an infectious disease. The industrial hygienist will become a very important source of health, safety, and environmental information for local, state, and federal agencies, emergency planning committees, healthcare professionals, public and private emergency response organizations, business leaders, and incident commanders. With their background in anticipation, recognition, evaluation, and control of hazards, industrial hygienists can provide a wide range of expertise. These professionals can advise the emergency response community on the means to effectively identify, manage, and ultimately control health, safety, and environmental risks associated with a pandemic outbreak.

Although the industrial hygienist has the requisite skills to effectively communicate risks based on complex scientific data and field information, it is understood that many may not have direct experience in emergency response and preparedness or experience with a pandemic. However, the skill set of the industrial hygienist would include the ability to ascertain, characterize, and evaluate various hazards that arise during a pandemic. Industrial hygienists have a strong understanding of PPE, respiratory protection, contamination control, decontamination principles, sampling and analytical methods, and other related areas. Whether in emergency planning or during an actual pandemic response, industrial hygienists can play a vital role in helping the emergency planning and response community deal with issues of risk, exposure, and protection. They can also help with the challenging communications between various parties such as the incident commander, healthcare providers, private sector teams, the general public, and business leaders.

In the preparedness phase, industrial hygienists can provide valuable information on the types of hazards that may be expected during a pandemic outbreak. Industrial hygienists can advise the emergency planning and response community on hazard control methods, such as ways to substitute or eliminate hazards that may arise from an incident. The industrial hygienist can provide important information about the types of PPE, including assistance with selection, limitations, and care and maintenance of equipment. During an event, the industrial hygienist can assist response personnel with information on the following:

- Proper donning and doffing of PPE
- Risks of wearing PPE, such as heat stress, lack of visibility, or increased accident risks
- Fit testing and fit checking of respiratory protection
- Proper methods for decontamination and disposal of equipment and clothing

Industrial hygienists can also help explain, particularly to the healthcare community, the value of using respiratory protection when dealing with airborne infectious diseases. Industrial hygienists are in a good position to communicate the capabilities and limitations of respiratory protection, as well as sampling data and analytical methods. Additionally, industrial hygienists can explain how sampling results can be affected by external factors. In general, industrial hygienists can also help by advising on:

- Plant operations that will be affected and what actions will be necessary to protect workers, the public, and the environment.
- Controls or barriers necessary to protect workers from hazardous agents.
- Cleaning and disinfection processes and agents, as well as methods for employees to use them safely.
- Administrative controls needed to reduce or minimize worker exposures, such as isolation or separation of workers, including in public spaces like lunchrooms or lavatories. This may also include policies on worker screening or testing.
- Training sessions and materials required to keep workers informed of policy and procedural changes.
- Awareness of health and safety issues that may come up in different situations, assuring that protection of workers and the public is maintained.
- Production of factual informational materials as needed to advance understanding of key environmental, health, and safety issues and encouraging preparedness and response collaboration among business, government, healthcare professionals, responders, workers, and the general public.

- Preparedness, by supporting training of response personnel and designing exercises and training drills.

K. Lessons Learned

- The media used for communication during a pandemic need to be socially and culturally appropriate and provided in languages and at reading levels appropriate for the audience.
- The potential fear and anxiety of the intended audience need to be addressed.

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VII. Sensors, Data Analytics, Tracking, and Management

A. Sensor Technology

Recent advances in Biotechnology have opened up a wide variety of screening tools for use in a pandemic. Generally, all instruments have limitations or tradeoffs in specificity and/or sensitivity. In broad terms, specificity is a measure of how well a test measures true negatives. Sensitivity is a measure of at what level and how often a test identifies true positives. Ideally, instruments should be both highly specific and highly sensitive. However, specificity and sensitivity are in balance, and obtaining a highly sensitive test means giving up on some specificity—the opposite of which is also true. Therefore, choosing the appropriate sampling device can be a dilemma when an industrial hygienist must choose one over the other. A good source of information on this subject for industrial hygienists is found in the NIOSH Manual of Analytical Methods, as well as in beginning statistics textbooks and other sources.[1,2]

1. *Near Real-Time Detection and Field Portable Devices*

Immunochemical tests are a method for determining the presence or absence of certain biomolecules. Much like an at-home pregnancy test, the lateral flow immunoassay (LFIA) and the enzyme-linked immunoassay (commonly known as the ELISA) can be made affordable and disposable (https://www.healthline.com/health/elisa).[3] These methods gained popularity during the COVID-19 outbreak as a means of quickly testing for presence or absence of proteins associated with infection. The ELISA works by using antigen-antibody combinations that include an enzyme-labeled antigen or antibody that binds with a ligand (typically a protein antigen) receptor. The enzyme activity is then measured based on a color change that identifies the presence or absence, and relative concentration, of the ligand in the sample. Depending on the situation, antibody or antigen testing may be a potential screening tool to determine who has been exposed (antibody testing) and who is currently infected (antigen testing).

There are a few drawbacks to this type

of testing. Is it better to detect ultra-low quantities with a high degree of accuracy? Typically, you would want a highly sensitive test to minimize Type II errors. Are you looking to rule out those samples that do not contain the agent of concern? In those situations, you would want a test with high specificity, avoiding Type I errors. Some studies have shown that there can be high false negative rates for COVID-19 antigen testing, with only 11% to 47% of the polymerase chain reaction (PCR)-confirmed cases detected by ELISA.[4]

These tests can be useful for screening a population to detect for presence of a pathogen of concern in a community. They are not good at confirmatory testing that specific individuals within the population have antigens for the pathogen of concern.

2. *Field Portable Polymerase Chain Reaction Testing*

PCR is a method for amplifying RNA or DNA from small samples to large sample sizes. This allows for use of gene sequencing or traditional genetic marker testing to confirm the presence or absence of genetic markers with a high degree of accuracy. Third generation microminiaturization of this technology has allowed for the development of portable field units. This technology is still relatively costly to deploy, but commercially available units are now obtainable for gene sequencing of select pathogens (e.g., SARS-CoV-2), which may make it feasible to perform surface testing for large facilities.

Like all PCR methods, the primary drawback of this method is its inability to distinguish viable or active pandemic agent nucleic acid from nonviable or inactive pandemic agent nuclei acid, as only the presence or absence of a particular nuclei acid sequence is determined. Another drawback is that portable PCR methods, as currently developed, are geared toward surface sampling, although air sampling can be performed using integrated sampling and laboratory analysis.

3. *Infrared Thermometers*

During a pandemic, employers may want to screen their workforce for symptoms of pandemic agents. Potential screening methods include pre-workplace entry for signs and symptoms specific to the known health effects of the pandemic agent. An example of screening for SARS-CoV-2 can be reviewed at https://www.cdc.gov/coronavirus/2019-ncov/community/guidance-business-response.html.[5] For example, a common symptom of influenza-like illness (ILI) is a fever; however, elevated temperatures are associated with many illnesses, and although useful, temperature measurements may not be specific enough to be effective. During the SARS-CoV-2 pandemic, the Centers for Disease Control and Prevention (CDC) recommended screening for ILI using contactless or infrared (IR) thermometers. However, the CDC cautioned that employers should “Ensure screeners are trained on proper use and reading of thermometers per manufacturer standards; improper calibration and use can lead to incorrect temperature readings.”[5] Training and properly calibrated equipment are important because the “standard” is based on an internal core body temperature of 101.4°F for determination of fever. However, surface forehead temperature readings from an IR thermometer may be 1–2°F (1°C) cooler than the internal core body temperature.[6]

Although this is a quick, inexpensive way to identify personnel who may have a nondescript illness that may be community spread, it does not identify all individuals who are definitively infectious. If developing a pandemic response, additional measures should also be used to identify potentially infectious individuals. Of note, OSHA determined in its “Guidance on Returning to Work” that “If an employer implements health screening or temperature checks and chooses to create records of this information, those records might qualify as medical records under the Access to Employee Exposure and Medical Records standard (29 CFR 1910.1020).”[7]

4. *Use of Emerging Wearable Technology for Screening*

There are a variety of wearable sensors now commercially available for use at an affordable price. With the advances in smartphones over the last decade, we have seen the availability for self-monitoring that is unparalleled in human history. Commonly available items such as fitness and workout devices and any number of other devices are available to track metabolic data. Measurements can include heart rate, blood pressure, oxygen saturation, and respiration rate. Through use of personal statistics and cloud computing, analysis of large data sets makes it possible to determine decreases in performance compared to an individual's baseline.

Although it may be tempting for employers to monitor these data from their employees, this could have legal ramifications and should only be done with consent of the worker and in adherence to privacy laws in the country in which the employer operates. In the United States, collecting medical data points with an associated name can be considered an item that would have to be retained in the employee's medical record under OSHA for the length of the employment plus 30 years.[8]

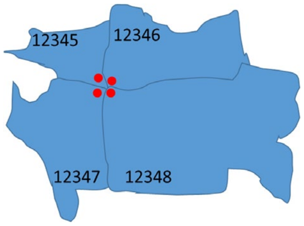
B. Data Analytics, Tracking, and Management

The CDC defines epidemiology as "the study (scientific, systematic, data-driven) of the distribution (frequency, pattern) and determinants (causes, risk factors) of health-related states and events (not just diseases) in specified populations..."[9]

The ability to detect an unusual case load should help to mitigate the effect of an outbreak. Using the traditional disease surveillance tools, the study on the efficacy of early disease detection has produced mixed results. Sugawara et al.[10] were able to confirm the feasibility and effectiveness of their early detection system, yet Steele et al.[11] concluded that more research was needed in early disease detection. However, with the utilization of information technology in addition to the traditional disease surveillance system (i.e., voluntary or mandated reports to public health agencies), there is potential to minimize the extent of the outbreak.[12]

Early detection systems or disease surveillance tools are a complex intermingling of physical infrastructures (hardware, software, and algorithms) and human capital of multidisciplinary teams of epidemiologists, healthcare workers, biostatisticians, database administrators, informational technologists, and health and safety professionals in all levels of government (local, state, and federal).

Utilization of spatial information in geographic information system (GIS)-based software enhances the early identification of disease clusters compared to traditional tracking databases. For example, an investigation may be needed using information that leads to four cases arising, all near each other. Spatial information easily identified those cases as an outbreak cluster. However, because all those cases fall in separate zip codes, the traditional database tracking method would likely not be able to identify those as an outbreak. The CDC's COVID-19 Information management is a good example of successful implementation of this tool.[13] Even though this is not a new technology, the use of spatial data is an emerging field in public health, especially in health and safety. Industrial hygienists and health and safety professionals need to learn more about this technology so that they can evaluate how best to protect their employees.



C. Data Management and Analysis

At all times, but especially during a pandemic, massive amounts of data are collected by various agencies or people. Therefore, it is critical that industrial hygiene data are part of a quality database. Well-designed databases include all pertinent information necessary for future analysis and require specific and consistent input. For example, if addresses are collected and entered, their entries must be consistent. Examples of variations in the same address are provided below:

123 Simple Road, Apt A, City, State, Zip
123 Simple Road Apt A, City, State, Zip
123 Simple Road, Apt A, City, State Zip
123 Simple Road #A, City, State, Zip
123A Simple Road, City, State, Zip
123-A Simple Road, City, State, Zip

These variations will take a toll on data quality and make it harder to identify and remove duplicate data. Health and safety professionals need to work hand in hand with informational system professionals regarding the design of the database and training frontline workers on how to properly enter data. This may require data input limitations such as templates, defined lists, format and content restrictions, etc. to ensure the data meet uniform search and query criteria. The concept of garbage in, garbage out (GIGO) is important when we rely on the analysis of our data. If bad data ever make it into the database, they may seriously compromise the information that we try to extract from it.

Data storage can be something as simple as a spreadsheet stored in a single computer to a midsize relational database to large backend databases. There is no one perfect database solution, and the right solution is the one that is based on available information technology resources (hardware and software) and personnel resources (database skill of the health and safety professional, organizational IT support). For example, a public health department in a small town is unlikely to need and/or be able to devote the time and resources to support a database that can track millions of cases and requires heavy IT investment.

As noted above, if an employer or organization decides to record/store the results of their screening (e.g., temperature or immunological testing), those records could potentially become protected health information under OSHA and/or the Health Insurance Portability and Accountability Act (HIPAA). As a result, records of these data might have to be retained and protected per the applicable regulation.

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Appendix 1: Plan for the Impact on an Organization and its Mission

A. Identify the Organization's Mission

Every workplace exists for a purpose, or mission. This purpose may be to provide a service, such as healthcare, transportation, or a pleasant dining experience, or it may be to generate a product. Many organizations develop mission statements to communicate this mission. This mission statement describes the purpose for which the organization exists and may include a statement of the organization's values and commitment to quality and customer service.

The mission statement supports the organization's vision. Vision statements express broad goals that the organization hopes to achieve long term.

Within a workplace, a number of employees perform work that directly supports the organization's mission. This includes healthcare practitioners in a hospital setting, bus drivers in a transportation agency, or production workers in a manufacturing plant, for example. Other employees within these organizations perform work that is important for the organization's success but do not directly support the mission. This could include planners, marketing personnel, and others whose job it is to grow the business but not directly support day-to-day operations.

B. Considerations of How the Mission May Change During a Pandemic

Concepts of supply and demand describe the interactions between sellers and buyers of a resource. When supply exceeds demand, prices decrease, and when demand exceeds supply, prices increase. The equilibrium of supply and demand during interpandemic periods can change abruptly when a pandemic hits. Lifestyle patterns change, and, either due to fear of the new disease or government proclamations, people spend more time at home and less time socializing, shopping, and spending time in public spaces. This affects supply and demand: There is an increased demand for contactless services.

There is increased demand for products that are protective against pathogens, such as hand sanitizer and personal protective equipment like gloves, surgical masks, and respirators. Manufacturers that build these products should be prepared to shift their operations and generate products in greater quantities to meet increased need, even if manufacturing these products is not directly aligned with their pre-pandemic mission.

Similarly, restaurants and other service organizations that profit from human socialization see a decrease in demand when people avoid face-to-face interaction and must change their business models to support changing patterns. Restaurants that can convert to outdoor dining or takeout service are best equipped to meet changing demands. The need for indoor waitstaff decreases while the need for delivery drivers increases.

The demand for face-to-face interactions decreases due to adherence to public health messaging or public orders. Demand for goods that can be purchased online increases while demand for goods that must be purchased in traditional "brick and mortar" stores decreases. Businesses can adapt by developing an online presence and supplementing existing purchasing options with delivery or curbside services. Healthcare providers can adapt to online, virtual appointments for services where feasible.

Workplace organizations that can adapt their business models to meet this change in supply and demand of goods and services can be successful during a pandemic and continue to meet their mission. Businesses that are unable to anticipate changing needs brought about by a pandemic and modify their practices accordingly may fail to survive.

C. Assumptions: Increased Absenteeism

One of the biggest threats to being able to accomplish the work organization's mission and goals is lack of personnel to do needed work. Workplace organizations should expect that staffing levels will decrease during a pandemic. Workplaces can, and should, implement strict workplace controls to ensure that employees who are sick do not enter the workplace. This is counter to American work culture, at least prior to 2020, in which reporting to work when sick symbolized commitment and dedication to the job.[1–3] Workplaces that lack paid sick leave and utilize attendance policies that penalize workers who call in sick contribute to a culture in which workers fail to stay home when sick.[4,5] Such practices are contraindicated during a pandemic, and work organizations should provide strong messaging and incentives to prevent sick employees from reporting to the workplace. Telework options, when feasible, can and should be utilized when consistent with business needs. This may require a higher level of trust that workers can efficiently perform their duties without direct oversight.

A pandemic, particularly one that has a high fatality rate and is easily spread, is a source of fear for many in the community. Employees who do not show symptoms of illness may refuse to report to work if they do not feel safe doing so, even if it means loss of income. This could include a large percentage of the workforce, especially when the workforce is organized and supported by Union leadership.[6] Under OSHA, employees have the right to refuse to perform work that is not safe, and the onus of proving that work can be performed safely during a pandemic falls on the employer.

Schools and daycares may close during a pandemic to limit community spread. Working parents of school-age children may be unable to report to work if childcare needs conflict with work assignments.

Increased absenteeism should be expected during a pandemic for many reasons, exceeding that which is to be expected due to seasonal colds and flu. Workplace organizations may therefore need to prioritize work that directly supports the organization's mission when staffing levels are insufficient to perform work during nonpandemic operations.

D. Assumptions: Supply Chain Impacts

Every workplace needs supplies in order to perform work. This could include raw materials used in production, tools and equipment, or personal protective equipment (PPE) for employees. Companies that manufacture these items are also dependent on employees to produce them, and absenteeism at these workplaces in turn reduces output. This can lead to shortages of needed supplies in ways that may be difficult to predict during the pandemic planning phase.

Transport and shipment of goods can also be disrupted when employees needed to work in warehouses and drive delivery vehicles are not available. Even if goods are produced, disruptions to delivery service can mean that they are not available when needed.

E. Assumptions: Changes in Needed Skill Sets

Moving from face-to-face interactions to electronic ones, telework, and a greater reliance on e-commerce requires an increased dependence on technology. Work organizations that have staff with skill sets to quickly develop and maintain new technology have an advantage over those who do not.

Changes in operations may require different skill sets than those needed during normal operations. Existing staff members may need to change their focus and either perform their jobs differently or take on new jobs altogether. These changes may need to happen quickly, allowing less time for planning than would be available for similar changes that occur during normal operations. As jobs and job tasks change, occupational and environmental health and safety (OEHS) professionals must continue to evaluate, and reevaluate, safety and health hazards.

F. Identifying Alternative Vendors/Suppliers

Because supply chains are expected to be impacted during a pandemic, it will be necessary to identify alternative supply sources for raw materials, PPE, and other needed supplies. These should be identified during the pandemic planning state because competition will be high for any supplier who is able to provide these needed goods and materials during pandemic conditions. Entering into contractual agreements with multiple suppliers during the pandemic planning phase can provide more options and greater flexibility once a pandemic starts.

G. Developing a Stockpile Plan

Just-in-time ordering practices can exacerbate risk. Work organizations can anticipate critical supplies that may be difficult to obtain during a pandemic and purchase these in advance. Stockpiling these materials may be a useful strategy if budget and storage space allow. The decision to stockpile certain items is one that must be carefully considered.

For example, demand for alcohol-based hand sanitizer increases during a pandemic. In 2020, demand for hand sanitizer outpaced supply to the extent that non-FDA approved manufacturers began producing it. Quality control decreased, and some of these hand sanitizers were later found to contain methanol. Methanol is toxic and can be absorbed through the skin.[7] Many work organizations began stockpiling hand sanitizer in the early 2000s when planning for a predicted pandemic caused by Highly Pathogenic Avian Influenza Virus H5N1 and used these stockpiles during the

2009–2010 H1N1 flu pandemic. Those that did not replenish their stockpile did not have hand sanitizer available in 2020 when the COVID-19 pandemic struck.

Other employers replenished this stockpile, only to find that their stockpile of hand sanitizer had expired by the time it was needed in 2020. If a decision is made to stockpile items with expiration dates, it is important to rotate the stockpile.

Additionally, hand sanitizer is a flammable material, and storage quantities and locations must align with local fire district codes as well as OSHA and state plan regulatory requirements.

Employers also stockpiled N95 filtering facepiece respirators (FFRs) in anticipation of the predicted H5N1 pandemic, and many of these same N95 FFRs were still in stockpiles when the COVID-19 pandemic hit. N95 FFRs also have limited shelf lives: By 2020, elastic head straps were often brittle, and face covering materials could have degraded.[8] Like hand sanitizer, stockpiles of N95 FFRs should be rotated so that they are used before their expiration dates.

H. Identifying Security Needs

As many needed supplies will be difficult to obtain, any workplace organization that has managed to obtain desirable items through stockpiling or agreements with vendors will need to secure these items. They will need to be stored in locations that can be locked, and measures will need to be taken to prevent access by those outside the workforce.

The value of the stockpiled items may be high enough that additional security personnel need to be hired to protect them. Security staff, and additional equipment including cameras, may also need to be increased in order to protect vacant buildings from vandals and/or squatters.

I. Building Maintenance

Building occupancy may be reduced if a large portion of the workforce is absent or working remotely. Still, ongoing building maintenance will be required. Preventive maintenance tasks, including HVAC system and plumbing maintenance, need to be performed regardless of building occupancy. Routine visits to buildings should also be conducted in order to identify any new damage to buildings from environmental or other causes, leaks and mold growth, and pest intrusions.

Work organizations should plan accordingly to ensure that sufficient maintenance staff will be available to perform these functions while assuming that a significant portion of maintenance staff may not be able to report to work.[9]

J. Developing a Ready, Willing, and Able Workforce

Employers can reduce absenteeism, and associated business risks, by working to build a *Ready, Willing, and Able* workforce.

- *Ready* refers to whether an employee can actually come to work. If family or household needs are pressing, the employee may need to focus on these immediate needs and will not be able to come into work. For example, school closures and lack of childcare will impact the ability of working parents to report to work in a pandemic. Employers may be able to accommodate working parents by assisting with childcare resources, allowing workers to perform remote work, or allowing flexible scheduling (such as allowing parents to work odd shifts). Employees may also need to quarantine or care for ill family members, and this will prohibit them from reporting to work.
- *Willing* refers to the likelihood that an employee will report to work in the absence of other obstacles. This is often influenced by the employee's perception of the degree of hazard: Employees who believe that their employer is able to adequately provide for their safety are more likely to come into the workplace than those who do not. OEHS professionals can contribute greatly to the willingness of their organization's employees to come into work by providing due diligence in evaluating and controlling hazards and communicating these actions to employees. Employees from workplace organizations that have strong positive safety cultures pre-pandemic are more likely to trust that their employers will also keep them safe when a pandemic hits.
- *Able* refers to the skills and knowledge that will be necessary to perform work during a pandemic. Employees' job tasks and responsibilities may change during pandemic operations, and they may need training or skill development in order to successfully perform these tasks and meet new job expectations. Additionally, this work may need to be

performed while wearing additional PPE and incorporating use of new administrative and engineering controls, which may be uncomfortable and unfamiliar in a time of enhanced stress.[6]

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Appendix 2. Developing a Business Continuity Plan

A. The "All Hazards" Continuity of Operations Plan

When an emergency occurs, workplaces may need to dedicate specific resources to respond to the emergency while at the same time maintaining business operations. Continuity plans, which may be called Continuity of Operations Plans (COOPs), Business Continuity Plans (BCPs), Continuity of Government Plans (CGPs), or another industry-specific term, provide a framework for operations when resources may not be sufficient to operate as they do in normal conditions.

Most continuity plans are written to address an "all hazards" response. The concept of "all hazards" is an integrated approach in emergency and continuity planning that recognizes that although a workplace organization may be subject to many different threats and hazards, there is a common management approach to these hazards. Perfecting a management and operations system that is common to all types of emergencies increases efficiencies when an incident occurs: Personnel managing the incident are trained and capable to fulfill the roles that they are assigned, and learnings from previous responses or exercises can be used to improve the plan through the Deming Plan-Do-Check-Act cycle of continuous improvement. Organizations that adopt the National Incident Management System (NIMS) of emergency management utilize a common operating system and common language that allows responders from different agencies and employers to effectively work together in a response.

In general, the main body of the plan describes operations management functions common to all hazards. Specific types of emergencies, such as a pandemic, are addressed in plan annexes or appendices.

Some types of emergencies can destroy or damage property, buildings, and infrastructure. For example, earthquakes, tornadoes, and hurricanes can cause widespread damage in a relatively short period of time. They may impact a fairly wide area, but it is contained. A business that operates out of several distinct regions can continue to operate: Operations that cannot be conducted out of the impacted area can be shifted to nonimpacted regions until the impacted sites can return to normal operations.

A pandemic differs from these types of incidents in that there is not a direct impact on property and buildings, and infrastructure systems are expected to remain functional as long as staffing levels are sufficient to maintain them. Power and information systems remain functional. In this sense, planning for a pandemic is simpler than planning for an event that impacts infrastructure. However, pandemics are not limited to a single geographical area, and all regions are expected to be equally affected even if infection rates spike in different regions at different times. Pandemics are also slow events. Unlike events such as earthquakes, which occur over a period of seconds or minutes, or storms, which are over in hours or days, a pandemic occurs over a period of months or years. During a pandemic, workplace organizations should assume that continuity operations will remain activated for a significant period.

Another significant difference between a pandemic and other types of hazards is that a pandemic significantly impacts people. Although physical infrastructure remains in place and functional, the workers required to operate this infrastructure may not be ready, able, and willing to come to work. Pandemic plans must assume that the workforce will be significantly reduced.

B. Requirements for Continuity Plans

Presidential Policy Directive (PPD) 21, issued by President Obama in February 2013, requires that critical infrastructures (and the organizations that support them) develop and maintain COOPs in order to maintain the nation's resilience and support national essential functions.

Critical infrastructures identified in PPD-21 include:

- Chemical
- Commercial facilities
- Communications
- Critical manufacturing
- Dams
- Defense industrial bases
- Emergency services
- Energy
- Financial services
- Food and agriculture
- Government facilities
- Healthcare and public health
- Information technology
- Nuclear reactors, materials, and waste
- Transportation systems
- Water and wastewater systems.

Some of the infrastructures identified in PPD-21 are managed by public agencies and governments, whereas others are managed by private entities.[1]

1. *Perform a Risk Assessment*

The first step in developing an all-hazards continuity plan is to identify the significant threats and hazards that could impact a workplace organization. This will be impacted by area and geography: Organizations on the West Coast must consider wildfires and earthquakes, those in the Midwest must consider tornadoes, and those in the Southeast must consider hurricanes, for example. State, county, and local government organizations conduct hazard identification and vulnerability analysis (HIVA) to support their own emergency planning, and these HIVAs should be evaluated to identify regional threats and hazards that may impact the workplace organization. Additionally, processes within the workplace may pose specific threats that must be anticipated and addressed.

The threat of a pandemic is a global one, and all organizations should include pandemics in their risk assessment.

2. *Perform a Business Process Analysis*

A business process analysis (BPA) identifies functional processes that support an organization's mission essential functions. This includes identification of workflows, activities, personnel, systems, resources, and facilities necessary to support these processes.

The BPA identifies the following employees:

- Employees that perform *essential functions* that directly support the organization's mission essential functions, noting that the organization's mission in a pandemic may not necessarily be identical to its non-pandemic mission. Some organizations use the term *critical functions* instead of essential functions; the use of this term is not to be confused with "critical infrastructure."

- Employees that perform *essential supporting activities* (ESAs). ESAs do not directly support the organization's mission essential functions but support the employees that do. For example, employees who perform essential functions are unlikely to be willing to do this work if they do not get paid, and therefore the payroll function should be identified as an ESA. Human resources and occupational and environmental health and safety (OEHS) professionals are also important ESAs and should be identified as such in the plan.
- Employees that perform *important functions*. Important functions are critical to the long-term success of the work organization but can be delayed in an emergency. During a pandemic, when absenteeism is high, employees who perform important functions may need to be reassigned jobs categorized as essential functions or essential supporting activities if that can be done safely. The OEHS professional should be prepared to work closely with these employees during continuity operations to ensure that they have sufficient safety training and equipment to do newly assigned work. If employees who perform important functions do not have sufficient knowledge and skills to perform alternate assignments, they may not have work to do when their normal work activities are delayed. Because employees who perform important functions will be critical when the organization returns to normal operations, the plan should identify ways in which these employees can be supported during continuity operations so that they are available to return to work when needed.

3. *Perform a Business Impact Analysis*

Once the BPA is complete, the planning team evaluates the threats that could interfere with the workplace organization's ability to meet its mission essential functions. (Note: NFPA 1600 guidance combines the BPA and the business impact analysis (BIA), and the Federal Emergency Management Agency (FEMA) guidance describes these as separate steps.)[2] Such threats could include reduced availability of supplies and raw materials due to impacts to the supply chain or transportation, impacts to buildings or infrastructure, or disruptions in communication systems.

In a pandemic, absenteeism is a significant impact that should be identified in the BIA. Management needs to follow advice from public health agencies in limiting the number of people who can be physically present in a workplace; otherwise, employees may not come into work because they are ill or need to quarantine after they have had contact with someone who is. If schools and daycares are closed, working parents will need to stay home to care for young children. Employees may also fail to report to work if they are not ready, able, and willing to do so.

The reduction in the number of employees available to perform essential functions and essential supporting activities is an impact that must be identified in the BIA. This is of particular significance in planning for a pandemic.

4. *Risk Mitigation*

Once potential business impacts are identified, steps can be taken to mitigate the effects of these impacts and reduce the risk that they will prevent a workplace organization from meeting its essential functions, much like the process followed when completing a Job Hazard Analysis.

In a pandemic, a primary risk is the reduction in the available workforce because workers become ill or will not come to work in the first place. Workplace transmission of disease can lead to outbreaks; if transmission is widespread, workplaces may need to shut down. OEHS professionals play a significant role in mitigating this risk through identifying, recommending, and implementing workplace controls, including social distancing, flexible scheduling, personal protective equipment (PPE), and engineering and administrative controls discussed in previous sections.

Risk mitigation should also address the threat of impacts to the supply chain. Alternative suppliers should be identified that can supply needed materials in the event that the usual suppliers cannot. If necessary, contracts should be secured during the planning phase.

Risk mitigation may include having employees work in different locations. They may be allowed to work from home or may be moved to new work facilities that better promote social distancing and other controls. Workers who normally perform important functions may be reassigned to perform essential functions or essential supporting activities. Changes to work may necessitate additional safety review, including ergonomics, fire and life safety, emergency action plans, noise, and toxic exposures. If job assignments change, additional training may be needed, including required safety training. Additional PPE may be needed to address hazards from new or modified work, and this must be compatible with PPE needed to protect from pandemic-related hazards.

OEHS professionals can increase the probability that employees will be ready, willing, and able to work by building resilience through occupational safety and health programs and training and ensuring that both employees and their families are individually prepared for disasters (including pandemics). Employees who believe that their employers will protect their health and safety during a pandemic are more likely to be willing to come to work. The safety culture that exists in the workplace prior to the pandemic will influence their beliefs about management's commitment to safety when the pandemic occurs. Workplaces that have implemented strong and effective safety programs will find that this serves them well when continuity plans must be activated.

5. *Identifying Resource Needs*

Once risk mitigations are decided on, resources must be obtained to support them. Resources likely to be needed in greater than usual quantities during a pandemic include:

- Handwashing supplies
- Hand sanitizer
- Respirators
- Gloves and other PPE
- Cleaning and disinfecting supplies
- Laptops and other equipment to support work-from-home strategies
- Information technology support
- Internet connections and hot spots
- Enhanced video conferencing capabilities

6. *Building the Plan*

The final step in planning is to actually build, or write, the plan.

The plan should be written clearly enough that it can be followed under less-than-ideal workplace conditions by personnel who may not have been involved in preparing it. The plan should also be flexible. Despite best efforts in planning, each disaster, and each pandemic, is unique, and planned strategies and procedures will need to be modified when the plan is activated.

The OEHS professional can ensure safety is accounted for in continuity operations through direct participation in plan development. Specific steps that the OEHS professional can take at this stage include:

- Preparing safety plan templates that can be modified and used in a pandemic event
- Preparing training materials
- Preparing fact sheets that can be given to employees, such as sheets that describe proper use of PPE or other controls[2–5]

7. *Exercising the Plan and Continuous Improvement*

Once developed, the continuity plan should be tested on an ongoing basis through exercises and drills. FEMA provides guidance for conducting exercises under the Homeland Security Exercise and Evaluation Program (HSEEP), which provides a framework for designing and conducting exercises and evaluating the response. Exercises are an opportunity to test capabilities and assumptions prior to the occurrence of a pandemic or other emergency. Deficiencies and areas needed for improvement are documented and evaluated in an After-Action Report (AAR). Action items identified in the AAR can be addressed, and the plan updated, in a cycle of continuous improvement.[6]

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Appendix 3. Shutdown and Reopening

A. Coordination with Public Health Agencies

The World Health Organization (WHO) issues international regulations that member states agree to follow. These regulations give the WHO Directorate the authority to declare an Emergency of International Concern. The WHO has identified the following four pandemic phases:

- The *interpandemic phase*, or the period between pandemics when there is no spread of novel pathogen
- The *alert phase*, in which a novel pathogen has been identified
- The *pandemic phase*, during which global spread is occurring
- The *recovery phase*, when infections decrease, there is a reduction in global risk, and the response can be de-escalated. This is followed by a return to the interpandemic phase.[1]

In the United States, pandemic response is coordinated by the Centers for Disease Control and Prevention (CDC). In turn, state health departments coordinate response at the state level, and public health agencies coordinate the response at the local level. Pandemic plans developed during interpandemic phases should align along all levels of government, although during the response or pandemic phase, individual health departments may or may not follow guidance and direction issued by the CDC. Pandemic plans developed within the private sector should in turn align with local government plans and with suppliers and customers, accounting for interdependencies.

Governing officials at the federal, state, and local levels have authority to issue emergency rules to control spread of novel pathogens. This can include measures such as prohibiting public gatherings, closing schools, or even issuing quarantine orders.

Private businesses may or may not be able to continue to operate when government orders are issued. Private businesses that are considered critical infrastructure, or that support critical infrastructure, must continue to operate despite pandemic conditions and are not allowed to shut down. Other businesses may be deemed nonessential and ordered to close to contain pathogen spread. In the absence of government mandates, business leaders must make their own decisions to close, continue to operate as normal, or to operate following a modified or scaled back business model.

B. Decision Making Based on Transmission and Severity

An emphasis on pandemic planning took place in the early 2000s when planning efforts focused on the threat of Highly Pathogenic Avian Influenza (HPAI) H1N5. The WHO identified response actions that would be implemented based on spread of a novel virus and how widely outbreaks were occurring, including implementation of containment measures when there was evidence of human-to-human spread. This approach was used in the initial stages of the 2009 H1N1 pandemic; however, it was criticized as excessive by the public when H1N1 did not turn out to be as severe or deadly as HPAI H1N5. In response, the WHO issued updated guidance that considered severity of disease in addition to transmission.

The CDC has developed assessment tools to consider transmissibility and severity of a novel virus using the Influenza Risk Assessment Tool (IRAT)[2] and the Pandemic Severity Assessment Framework (PSAF)[3] with the intent that the results of such assessments would guide decision making. This analysis by Freitas et al. showed that the H1N1 pandemic was of low severity, similar to a bad seasonal flu season, and the COVID-19 pandemic was similar in severity and transmissibility to the 1918–1919 influenza pandemic.[4]

C. Goal Setting: Maintaining Case Rates at a Manageable Level

A widely transmissible, highly severe novel virus has great potential to overwhelm the healthcare system. Ultimately, pharmaceutical interventions such as vaccinations and effective treatments can be utilized to save lives and limit spread, but these are not available in the months of a pandemic. The Federal Emergency Management Administration (FEMA) as well as the CDC call out the need for Nonpharmaceutical Interventions (NPIs) to control spread until pharmaceutical treatments are developed, tested, approved, and become widely available to treat those who contract the disease and vaccinate other vulnerable members of the population.[5–7] These NPIs include measures taken by public health agencies, such as decisions to prevent large gatherings and close schools, and measures taken by occupational and environmental health and safety (OEHS) professionals, including engineering and administrative controls and use of personal protective equipment.

Disease will continue to spread during this period, but lives can be saved by limiting spread and disease incidence to maintain a level that the healthcare system can manage.

Hospital capacity must be maintained. There are a little more than 900,000 staffed hospital beds in the United States in any given year.[8] These beds are occupied by patients who have cancer, have experienced heart attacks or strokes, or have any number of other conditions. In a severe pandemic, up to a million patients may ultimately need to be hospitalized to treat disease caused by a novel pathogen. This, along with the baseline number of hospitalized patients, could easily overwhelm the healthcare system.

When the healthcare system is overwhelmed and there is a shortage of beds, ventilators, or other needed equipment, healthcare workers must make tough choices as to which patients receive limited health resources. For example, would a 35-year-old patient receive priority over a 50-year-old patient, since saving the 35-year-old would mean more years of life saved? Would the decision be the same if the 35-year-old had pre-existing health conditions and the 50-year-old did not? How do concerns of social and racial justice play into these decisions? Decisions on how crisis standards of care are administered should be made during pandemic planning in the interpandemic phase and should be transparent to the community to avoid any real or perceived instances of bias. Such decisions should not be left to individual healthcare workers to make in moments of crisis.

Ideally, community and workplace controls should be implemented to maintain hospital capacity and prevent the need to resort to crisis standards of care.

D. Balancing Economics, Public Health, and Implementation of Controls

Shutting down the economy or even implementing workplace controls during a pandemic comes with an economic cost, but this must be balanced against lives saved. The idea that human life can be reduced to a monetary value is an uncomfortable one. However, this came to light in the 1980s when the general public learned that the Ford Motor Company had decided, based on a cost-benefit analysis, not to install a safety feature that would protect passengers from exploding gas tanks on the Ford Pinto. Public outrage at this decision tarnished the image of both the Pinto car and the Ford Motor Company. The company also paid millions of dollars in damages.[9]

The Environmental Protection Agency (EPA) has long considered the value of a statistical life (VSL) or value of risk reduction (VRR) in considering cost-benefit impacts of environmental policy. EPA recommends that a VSL of $7.4 million be used (in 2006 dollars and adjusted for the year of analysis), equating to $9.5 million in 2020. If this VSL is used to estimate the cost of the 330,000 lives lost to COVID-19 in 2020, this would calculate out as a monetary value of more than three trillion dollars. This value can be used in calculating the cost-benefit analysis of implementing workplace controls and other NPIs.[10–13]

E. Compliance with Regulatory Requirements (OSHA, State Plans) and Reducing Liability

Employers that remain operational during a pandemic, whether by choice or by mandate, must continue to meet regulatory rules established by the Occupational Safety and Health Administration (OSHA) or by state plan agencies. Inspectors may pay particular attention to how an employer implements their Respiratory Protection and Hazard Communication programs under pandemic conditions and may cite additional infractions under the General Duty Clause. OSHA and state plan agencies have authority to issue emergency standards to address new and emerging hazards, including novel pathogens.

Cases of illness contracted in the workplace must be recorded on an employer's OSHA 300 log and may be covered by workers' compensation.[14,15]

Additionally, employers who willfully expose their employers to hazards may be subject to criminal liability.

Employers must evaluate their ability to meet regulatory requirements, as well as their ability to reduce civil liability by preventing disease spread through effective use of workplace controls, when making decisions to close or limit operations. Documented spread of disease within a workplace may require temporary closures as well.

F. Reopening Workplaces After Temporary Closures to Control Spread of Disease

Workplaces may implement full or partial closures to control spread after one or more employees has contracted the novel pathogen. Current guidance from CDC, state departments of health, and local public health agencies should guide these decisions. Closures should be strongly considered if a workplace experiences sustained transmission.

Likewise, guidance from CDC, state health departments, and local public health agencies should be considered when making the decision to reopen a workplace. Factors to consider in making such decisions include survival and transmissibility of the pathogen from the environment and incubation and transmission timelines in people.

To prevent environmental transmission, workplaces may opt to remain closed until it is expected that any pathogen on surfaces is no longer viable. Cleaning and disinfection of the workplace can enable faster reopening, although health risks to those conducting cleaning and disinfection are increased. Surface testing and wipe samples can provide greater clarity as to when it is safe to reoccupy facilities, and reopening decisions can be based on the results of these samples when they are available.

Reopening workplaces may involve more than simply verifying the removal or inactivity of the pandemic agent. Utilities that have been offline for extended periods may require maintenance and/or startup procedures that may have their own hazards and risks, depending on the length of time the systems were offline. For example, fungal and other biological growth (e.g., Legionella) or contamination may be present and disseminated by air or water systems if they are not properly maintained or treated prior to startup.

Any personnel who may have been exposed to the pathogen during the period of workplace spread should self-quarantine for the time recommended by public health agencies. If this includes high numbers of a workforce, a workplace may not be able to reopen until a sufficient number of employees have completed this quarantine period.

G. Reopening Communities

The Recovery Phase of a pandemic begins when infections decline and there is a decrease in global or community risk. This may occur due to a natural decline in infections resulting from acquired herd immunity or because of sufficient administration of effective vaccines.

Reduction in risk can also be achieved when effective disease treatments are available. For example, when Tamiflu is administered to newly infected influenza patients, it can significantly shorten the length of illness and decrease severity of disease, resulting in a lower rate of hospitalization and death. Novel influenza viruses may or may not be susceptible to Tamiflu. Early in the 2009 H1N1 outbreak, it was demonstrated that the novel H1N1 virus could be treated with Tamiflu. A similar early treatment was not available for the novel COVID-19 virus in 2020, giving greater importance to controlling spread through NPIs.

The effectiveness of NPIs such as workplace controls can play into reopening decisions. Controls that are effective in preventing workplace transmission can allow a business to open even when community transmission remains high. This should be considered in cost-benefit decisions on the implementation of engineering and other controls.

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Appendix 4. Special Consideration for Workers with Pre-Existing Medical Conditions

Hypertension, cardiovascular disease, diabetes, chronic obstructive pulmonary disease (COPD), malignancy, and chronic kidney disease are considered risk factors for increases in severity and complications of COVID-19 infection. There are also diseases/comorbidities of aging. The combination can significantly increase the risk of complications of COVID-19. For these groups of workers, their "impairments" do not make them unable to perform the essential duties of their jobs. However, they should be allowed to work from home where feasible.

The Centers for Disease Control and Prevention (CDC) also recommends that employers consider offering employees at higher risk for severe illness duties that minimize their contact with customers and other employees (e.g., restocking shelves rather than working as a cashier, if the worker agrees to this).[1] Some may argue that workers who are not willing to attend work for fear of poor complications if infected should not be considered unfit to work; rather, these individuals should be seen as having a lower risk tolerance (i.e., a personal choice). The employer should develop a policy to deal with this perceived danger.

Even though the evidence for pregnancy and COVID-19 complications are not equivocal, it is recommended that pregnant workers should be allowed to work from home if feasible.

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Appendix 5. Industries with Unique Challenges

Many industries have experienced unique challenges during the COVID-19 pandemic. Industries as disparate as Primary/Secondary Education and Meatpacking pose dilemmas to the industrial hygienist who needs to evaluate how and where to position source, pathway, and receptor controls. These decisions will be informed by several variables that present challenges to the industrial hygienist. Examples of industries that have posed these challenges during the COVID-19 pandemic and could cause problems during future pandemics are illustrated in Tables A5.1 and A5.2. The industrial hygienist could posit many other industries and other workplaces with unique challenges not included in the tables, such as the ability to work at home and availability of paid sick days.

Where the table has an “X” in a column and row, the “X” refers to a challenge in that industry or workplace. The rationale for why an “X” is placed in the column is detailed in the text following the tables.

Table A5.1, Part A

	Manufacturing	Food Production	Gig Workforce	International Work
Social Distance	x	x	x	x
Partitions	x	x		
Source Control		x	x	x
Demographics	x	x		x
Ventilation	x	x		x
Testing		x	x	

x = Presence of unique challenges

Table A5.1, Part B

Manufacturing	
Social Distance/ Partitions	Workers are required to move around frequently and work close to each other, which makes using partitions and social distancing difficult
Source Control	Face coverings/face shields are being provided/enforced, reducing the likelihood of transmission.
Demographic	Many individuals with this job are in at-risk populations (minority workers).
Ventilation	Ventilation is needed in some settings, so organizations would have to work with engineers to ensure adequate ventilation to reduce spread.
Testing	Organized testing is implemented throughout organizations.
Food Production	
General Sanitation	Increase in sanitation for safety precautions
Social Distance	Production lines dependent on machine are preset and hard to change.
Partitions	Workers are not in one distinct spot all day, so partitions would be in the way or hard to organize.
Source Control/PPE Availability	Company would have to find large volume of PPE, difficult (especially early)
Demographic	High volume of immigrant workers (~27%), vulnerable demographic[1]
Ventilation	Cross-contamination has to be monitored so ventilation must be carefully maintained.
Testing	Large volume of workers requiring testing, and the frequency of testing can be a challenge.
Gig Workforce, Shared Rider Drivers	
Source Control/PPE Availability	Independent contractors will have to be responsible for their own PPE, could have barriers to access (cost, availability). Example: Uber offering “Clorox” wipes to drivers. Very limited supplies available.
Testing	No organized testing through companies; workers will have to be responsible for accessing their own testing; riders not necessarily required to have testing done
Social Distance	Uber driver and rider in confined space—6 feet of distance is hard to maintain
Ventilation	Weather depending... normally required to open windows
Demographic	Broad and diverse population necessitates messaging many different ethnic groups
Partitions: Staff & Riders	Uber does not provide partitions to all drivers—inequitable access to safety
International Workplaces: UK Example	
Social Distancing	Many businesses and workplaces have put occupancy too high for proper social distancing, resulting in large outbreaks in the workplace.
Source Control/PPE Availability	Great Britain’s National Health Service (NHS) had difficulty distributing the PPE they wanted people to wear (N95 and surgical).[2]
Demographic	New variants could affect people younger than the earliest strains of SARS-CoV-2; some industries have taken a harder hit than others.
Ventilation	Indoor ventilation concerns are the same as those in the United States.

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Table A5.2, Part A

	Healthcare	Primary Ed K-12	Higher Education	Long-Term Healthcare Facilities
Distance: Staff	x	x	x	x
Distance: Patients/ Students	x	x		x
Partitions: Staff	x			
Partitions: Patients/ Students	x			
Source Control: Staff		x	x	x
Source Control: Patients/ Students	x			x
Demographic: Staff	x	x	x	x
Demographic: Patients/ Students	x			x
Ventilation: Staff	x	x		x
Ventilation: Patients/ Students	x	x		x
Testing: Staff	x	x		
Testing: Students/ Patients				

x = Presence of unique challenges

Table A5.2, Part B

Healthcare[1–3]	
Social Distance: Staff	Social distancing in hospitals and clinics may not be possible. Staff are continuously moving around and working closely with patients and other staff members, so social distancing is not ideal at times.
Social Distance/Partitions: Patients	Social distancing/partition measures between patients can be put in place; patients can be put in separate rooms with separate bathrooms, or, if the facility has an open floor plan, beds can be put at 6 feet with partitions installed. Additionally, in outpatient settings, telehealth is being implemented. Sharing the bathroom in a ward can be a challenge.
Partitions: Staff	Partitions are not easily implemented.
Source Control: Staff	Protects patients when placed next to each other, but it is also crucial to have PPE available for staff (they are required to wear more respiratory protection, such as N95); consideration for floor plan and certain areas should determine what PPE should be worn in that area
Source Control: Patients	Patients can be given source control (surgical masks) if they are diagnosed with COVID; however, it is not mandated. It could be beneficial in order to control nosocomial infections and protect staff. The use of PPE on patients can be a major challenge, especially with mentally ill patients.
Demographic: Staff	Hospitals face staff shortages, and many minority population staff are hit the hardest.
Demographic: Patients	Some populations are more likely to be diagnosed with COVID-19. This, in addition to other health issues and inequities, might cause these populations to have a higher chance of hospitalization. They may also be less likely to seek healthcare for various reasons, such as the inability to miss work, afford healthcare, etc.[4]
Ventilation: Staff	Staff in the hospital may not have access to adequate outdoor air sources in the hospital due to inadequate ventilation, which is difficult considering the amount of PPE they have to wear. The only source of outdoor air ventilation they can get is in break rooms, and hospitals have to ensure that break rooms are not in a location of air return. Operating rooms can also be turned into negative pressure rooms (since elective surgeries have decreased).[3,5]
	Many hospitals lack enough negative pressure rooms that help stop the spread of COVID through the air/between patients, especially if there are many patients with a respiratory disease. The direction of flow from clean areas to dirty areas can be a challenge.
Testing: Staff	There is downtime while awaiting results of screening tests, meaning some healthcare workers are unable to work during the testing period, especially if the hospital requires full testing like a body scan to see if there is anything present within the person's lungs.
	Many hospitals did not have the capacity to test for COVID-19 as patients or staff entered the hospital, and it may be difficult to test some people who come in through the emergency room. Appropriate isolation, PPE, and source control for patients are needed.
Higher Education	
Social Distance	Many communal spaces have high-density occupancy, e.g., dorms, showers, library, classroom, dining hall.
	Dorms have some of the highest density occupancy on campus.
	Elevators on campus
	Handling classroom capacity
Testing	Off-campus students not being tested; testing available to staff members and all students attending on-campus; decisions on how often to test staff and students (randomly, once a week, twice a week?). Who will be able to get voluntary testing on campus?
	Random testing might be a hit or a miss /may or may not be an accurate representation of cases.
Partitions	Between students and food staff
	Dividers between residence hall staff and students

Table A5.2, Part B (continued)

Higher Education (continued)	
Demographic	Typical university open campus means people not associated with the school could wander around campus and potentially spread the virus.
	Higher risk for older staff/staff with chronic conditions
	High risk for older family members of students who return home; Concerns with international students and ability to leave country
Ventilation	Outdoor air into buildings may be limited where few windows and doors are open; potential for use of HVAC upgrades (but they are very expensive)
Source Control/PPE availability	Contact tracing for students
	Medical app for self-diagnosis: campus clear/reporting systems
	Cleaning classrooms: is it done between classes? Are students responsible for their own area? How often are the spaces cleaned?
	Problem areas include music departments, voice training and playing wind instruments, and research with animals (need workers on site).
Long-Term Care Facility	
Shortage of Staff	Nursing aide turnover; low wages (median < $13.38 an hour); some staff work in multiple facilities at once, meaning there is more risk for exposure and spread.[6–8]
	No or minimal sick leave
Demographic	There is a higher number of workers with vaccine hesitancy working in nursing homes; 53% of registered workers in nursing homes are minorities, who are disproportionately impacted by COVID-19.[9]
Social Distance	Before the pandemic, loneliness was already a concern among older adults. With COVID-19, loneliness became a greater concern because it caused an increase in depression and health issues. The designed communal living spaces make it difficult for staff to provide individualized spaces for residents. Staff are advised to identify high-risk choking residents who may cough while eating and sanitize hands when switching from patient to patient.
Ventilation	According to the CDC, upgrades to and maintenance of HVAC systems in buildings must be rigorous. Maintenance and upgrades often depend on seasonal and environmental changes; ventilation needs may be specific to the patient's condition and COVID status.
Source Control/PPE	Severe shortages of PPE
Source Control: Patients/ Students	Memory loss illnesses such as dementia and Alzheimer's are more likely for the patients in nursing homes, making it difficult for them to remember the precautions of COVID-19.
Demographic: Patients/Students	The demographic of nursing homes contains elderly patients that are at a higher risk of negative impacts from COVID-19. According to a Harris Poll, only 47% of individuals over the age of 60 are worried about the impact of COVID-19.[10]
Partition	In some instances, closed doors and individual isolation can pose risks to resident safety (e.g., memory care units). There are unique barriers related to partitions and ventilation in circumstances where infection is suspected or confirmed but the resident requires their door to be open.
Primary Ed K-12	
Distance: Students	Can be difficult to ensure students stay separate from each other, especially younger children
Distance: Faculty	Have to interact with children and be in situations that require close contact, especially in emergencies
Source Control: Staff	Can be difficult to trace the source of COVID-19 as many teachers work in close contact with each other and their students
Demographic: Staff	Many teachers are women and have no childcare to resume in-class teaching[11]
Ventilation: Staff and Students	

Table A5.2, Part B (continued)

Primary Ed K-12 (continued)	
Testing: Staff	Classrooms require proper ventilation, but some do not have adequate windows/means for ventilation; it can be hard to ventilate in the winter.
Testing: Student	Not always possible. The frequencies of testing can be a challenge.

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