Reopening Public Facilities After a Biological Attack: A Decision-Making Framework

Committee on Standards and Policies for Decontaminating Public Facilities Affected by Exposure to Harmful Biological Agents: How Clean is Safe?, National Research Council

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Reopening Public Facilities

AFTER A BIOLOGICAL ATTACK

A Decision Making Framework

Committee on Standards and Policies for
Decontaminating Public Facilities Affected by
Exposure to Harmful Biological Agents:
How Clean Is Safe?

Division on Earth and Life Studies

Board on Life Sciences

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COMMITTEE ON STANDARDS AND POLICIES FOR DECONTAMINATING PUBLIC FACILITIES AFFECTED BY EXPOSURE TO HARMFUL BIOLOGICAL AGENTS: HOW CLEAN IS SAFE?

KENNETH BERNS (*Chair)*, University of Florida, Gainesville, Florida
RONALD M. ATLAS, University of Louisville, Louisville, Kentucky
MANUEL S. BARBEITO, Biosafety Consultant, Frederick, Maryland
JACQUELINE CATTANI, University of South Florida, Tampa, Florida
LEE CLARKE, Rutgers University, New Brunswick, New Jersey
CHRISTOPHER J. DAVIS, CUBRC, Inc., Buffalo, New York, and Washington, DC
PATRICIA FELLOWS, DynPort Vaccine Company, Frederick, Maryland
CHARLES N. HAAS, Drexel University, Philadelphia, Pennsylvania
THOMAS INGLESBY, University of Pittsburgh Medical Center, Baltimore, Maryland
HARVEY W. KO, Johns Hopkins University, Laurel, Maryland
R. PAUL SCHAUDIES, Science Applications International Corporation, Rockville, Maryland
MONICA SCHOCH-SPANA, University of Pittsburgh Medical Center, Baltimore, Maryland
JOHN D. SPENGLER, Harvard School of Public Health, Boston, Massachusetts
JAMES TUCCI, K&J Consulting, Cantonment, Florida
JAMES WILDING, Metropolitan Washington Airports Authority (retired), Glenwood, Maryland

Board on Life Sciences Liaison to the Committee

RANDALL MURCH, Virginia Polytechnic Institute and State University, Alexandria, Virginia

Staff

KERRY A. BRENNER, Study Co-director
EVONNE P.Y. TANG, Study Co-director
FRANCES E. SHARPLES, Director, Board on Life Sciences
EILEEN CHOFFNES, Senior Program Officer
BRIDGET K.B. AVILA, Senior Program Assistant (until March 2004)
SETH H. STRONGIN, Senior Program Assistant
KATE KELLY, Editor

Preface

The impact of bioterrorism was brought home to the American public in the fall of 2001. Although there had been earlier instances of bioterrorism, as well as threats and hoaxes in recent years in Japan and the United States, the juxtaposition of the biological attacks of 2001 to the events of September 11, and the use of highly lethal preparations of anthrax, had a profound effect on the national psyche. Private and government facilities alike were affected, and considerable challenges were encountered in the process of cleaning up the affected facilities. The decontamination efforts were heavily publicized, time consuming, and very expensive. Sampling and decontamination approaches and parameters had to be decided upon very quickly. Plans had to satisfy scientific criteria to show that individuals reentering the area would not become infected and, as important, address the concerns and fears of people who used the facilities. Eventually, all of the public and private facilities were successfully decontaminated (although there was a considerable delay, caused by financial concerns, in the cleanup of one private site). However, given the urgency, and lack of preparedness with which decisions were made in 2001 and 2002, it seemed likely that the process could be improved with advance planning. This study was requested to help provide a framework for the restoration of contaminated facilities should it be necessary in the future. Specifically, the study was undertaken to consider the question of "How clean is safe?" and to address the criteria that must be satisfied to determine that the site of a biological attack is fit to use again.

The 2001 anthrax attacks revealed our vulnerabilities, and suggested that a more widespread attack could have serious consequences for the ability of the country to function. Following the 2001 attacks, alternative locations were found so that essential work could continue. However, if a major transportation terminal

for planes or trains were to be taken out of commission, it would be extremely difficult or perhaps impossible to relocate those services elsewhere. In addition to the large costs of a cleanup, the financial consequences and impact on commerce and society could be enormous. If a larger number of sites were attacked and the areas that had to be cleaned up were more extensive, the costs could rapidly escalate to a level that might prove unsupportable (depending in some part on just how essential or irreplaceable each site was deemed to be). The final costs would depend on the approach taken to decontaminate, the parameters that need to be satisfied in terms of test results, the extent of testing, and the evaluation of acceptable risk. To make recommendations about these issues, the committee considered many questions.

What are the best ways to assess the presence of the agent? What are the best tests and how should they be applied? How much and what type of sampling is enough? How sensitive do the tests need to be? How many organisms constitute an "infectious" dose? What tests are necessary to declare an area safe? Risk analysis constitutes a major component of this study. The participation and confidence of the affected stakeholders in the process of cleanup and the overall response to a bioterrorism incident are crucial.

The recommendations of this report provide guidance on scientific and social science issues because both areas are important to creating a systematic approach to developing standards for effective remediation after a biological attack.

Kenneth Berns
Chair, Committee on Standards and Policies
for Decontaminating Public Facilities
Affected by Exposure to Harmful
Biological Agents: How Clean is Safe?

Acknowledgments

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Roy M. Anderson, Imperial College, London, United Kingdom
Peter Biggins, Dstl Chemical and Biological Sciences, Porton Down, United Kingdom
Margaret Coleman, Syracuse Research Corporation, Syracuse, New York
Baruch Fischhoff, Carnegie Mellon University, Pittsburgh, Pennsylvania
David Franz, Midwest Research Institute, Frederick, Maryland
Terrance Leighton, Children's Hospital Research Institute, Oakland, California
Harold Lewis, University of California, Santa Barbara, California
Richard Marchi, Airport Council International-North America, Washington, DC
Shelly Miller, University of Colorado, Boulder
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Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of

this report was overseen by R. Stephen Berry, James Franck Distinguished Service Professor Emeritus, The University of Chicago and Richard B. Setlow, Senior Biophysicist, Brookhaven National Laboratory. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author committee and the institution.

Contents

Executive Summary

In the fall of 2001 there were several incidents of bioterrorism in which preparations of *Bacillus anthracis* were mailed to public and private institutions. The acts led to 5 deaths from inhalational anthrax and to more than 20 cases of inhalational or cutaneous anthrax. More than 30,000 people were given prophylactic antibiotic therapy (Lane and Fauci, 2001). People were infected not only at locations where the contaminated envelopes had been opened but also at sites through which the unopened mail had passed, including postal distribution centers and local mail rooms. Decontamination was required at many locations.

Decontamination was an extensive undertaking, both for cleanup and for communication involving building managers, government agencies, a host of private- and public-sector experts, and affected building occupants and users. Decisions had to be made about which sites required cleanup, what method to use, how to determine the effectiveness of the cleanup, and how "clean" the building had to be for reoccupation. The responses of people who occupied the building in the affected areas and in other locations and those of other stakeholders had to be considered in the overall remediation effort. Responses ran the gamut from apparent confidence in decision makers to outright distrust and hostility. The stakes were high, and there was considerable stress attached to the uncertainties concerning the successful completion of the project. For these reasons, the significance of the social aspect of recovery from a bioterrorism attack cannot be overstated.

The cost of decontamination was significant. Remediation of U.S. Postal Service facilities alone cost more than $200 million. Clearly, it is desirable to control expenses, so it is of national interest to learn how to respond to and

recover from a bioterrorist attack in a manner that effectively reduces the risk posed by exposure to the biological agent to an acceptable degree of assurance and without incurring unnecessary expense. Factors to consider for effective response and recovery include the geographic extent of contamination, the timing and duration, and the method of decontamination, all of which are influenced by characteristics of the agent released. Underlying all of this is a question: "How clean is clean enough?" The original question placed before the Committee on Standards and Policies for Decontaminating Public Facilities Affected by Exposure to Harmful Biological Agents was "How clean is safe?" Is there a standard that we should anticipate, beyond which additional decontamination efforts would yield insubstantial benefit?

In response to the attacks of 2001 and their subsequent cleanup, the Department of Homeland Security funded a project called the Restoration and Domestic Demonstration and Application Program, which was run by the Lawrence Livermore National Laboratory (LLNL) and Sandia National Laboratories. As part of the study, the LLNL subcontracted to the National Research Council (NRC) to convene a committee of experts to consider the criteria that must be met for a cleanup to be declared successful, allowing the reoccupation of a facility. The committee specifically was asked to consider a scenario in which decontamination of a facility approaches completion, but it was not asked to review all issues that should be considered in the aftermath of a biological attack. Therefore, this report does not address in any detail the risk that such an attack would occur, the emergency response to an attack, the identification of the appropriate allocation of resources for research or response, or broader public health issues related to transmissible diseases. It does not recommend specific decontamination technologies, although such technologies are discussed to provide information for those who need to understand them to make informed decisions about reoccupation. Rather, the report reviews the key factors that influence decision making and lays the foundation for establishing standards and policies for relevant aspects of biological decontamination. Because the sponsors are seeking additional information for their demonstration project, this committee focused its effort on indoor facilities, and it uses an airport as a model.

The committee considered the issues outlined above and concluded that remediation must meet appropriate technical considerations from several perspectives, and it must be convincing to the stakeholders, especially the users of a facility. There is no single standard to apply to all situations. Thus, based on its scientific analysis of the available information, the committee outlined steps that would help achieve a socially acceptable standard for cleanup.

This report has 12 chapters, each containing information relevant to the decision about what constitutes "acceptable cleanup." It considers the history of biological weapons, the biology of 3 microorganisms that are considered threats for use in biological warfare, the nature of the response to infection, the issues associated with the determination of infectious dose and quantitative microbio-

logical risk analysis, the social issues involved in making decisions, reagents and techniques used in decontamination, approaches to detection and surveillance of microbiological contamination, and environmental factors in buildings that affect the distribution and accessibility of the agent to decontamination. Chapter 3 and Appendix D contain case studies on some of the buildings that were decontaminated after the 2001 anthrax attacks and on other facilities that have been cleaned after biological or chemical contamination. Because of the particular concern of LLNL, the final chapter specifically addresses the considerations that apply to a major airport.

What has become clear is that there are three levels of consideration in the approach to decontamination: The first is the fact that decontamination within a "reasonable" period is necessary and must proceed in a manner that is consistent with available knowledge and current regulations. The social aspect of decontamination and safe reoccupation—for example, stakeholder and occupant concerns—is another consideration. The third involves the recognition that there is a lack of information that could influence both the effectiveness and the cost of decontamination, a state of affairs that should be remedied. Findings and associated recommendations appear at the end of each chapter. Selected key findings and recommendations are summarized here.

The charge to the committee is addressed by discussions in five areas: infectious dose, natural background of microbiological flora of interest, risk assessment, past cleanup efforts, and residual contamination. Key messages of the report for each area are indicated here.

INFECTIOUS DOSE

The 2001 anthrax attacks called into question the state of knowledge on what constitutes the infectious dose for *B. anthracis*. Infectious dose is the term often used to denote the number of organisms it is believed are necessary to overwhelm host defense mechanisms and establish an infection that can lead to disease. The committee concluded that standard infectious doses for harmful biological agents that could be used as weapons cannot be determined with confidence because the infectivity and virulence of harmful agents can vary by strain, within species, and by type of preparation into weapons. Currently available data on dose–response relationships are not as extensive as demanded by modern scientific standards, and, in most cases, the human data cover only the exposure of healthy young adults.

NATURAL BACKGROUND

The committee acknowledged that natural environmental background concentrations of various microorganisms have been assessed in some areas and that most people in those locations tolerate exposure without adverse effects, perhaps

because those people have developed immunity gradually. The concept of natural background is difficult to apply in evaluating acts of bioterrorism in indoor public facilities because it is not likely that a detectable natural background of harmful agents, such as those under consideration in this report, would exist in indoor public facilities. Moreover, the agent used in an act of bioterrorism could be different from its natural form if it has been weaponized. (Weaponized microorganisms are processed to enhance stability, infectivity, environmental half-life, or ease of dissemination.)

RISK ASSESSMENT

Quantitative risk assessment models often are used to evaluate complex situations. The models have four steps: hazard identification, exposure assessment, dose–response assessment, and risk characterization. Although such models can be useful in assessing the risk of exposure to harmful biological agents after cleanup, the essential data to support thorough analysis via quantitative risk assessment are lacking for some agents that might be used as biological weapons.

PAST CLEANUP EFFORTS

A review of the *B. anthracis* cleanup after the events of 2001 provides insight about the approaches that should be used in the event of a future attack.

RESIDUAL CONTAMINATION

Some biological agents in their natural forms would likely degrade rapidly enough that extensive cleanup would not be necessary after an initial decontamination. However, a preliminary analysis of the agent might not reveal alterations that could influence its viability. Therefore, a full characterization would be necessary to evaluate the effect of genetic or physical modifications on its viability. After cleanup, continuous medical monitoring might be useful to ensure the safety of those who would occupy the decontaminated space.

A contaminated facility cannot be guaranteed to be agent-free even after cleanup because it is impossible to prove the complete absence of an agent. The committee was asked to consider whether there is a “safe” amount of residual contamination. It concluded that there is insufficient information to quantify a “safe” amount of residual biological agent in a decontaminated facility. Further research could provide information on host response to specific doses that would decrease the uncertainty and make a quantitative approach more useful. However, the risk different people or groups of people are willing to tolerate will always vary. Therefore, the issues related to decision making raised in this report will continue to be relevant. The report considers lessons from the response to the 2001 anthrax attacks and from other situations involving chemical or radiological

decontamination; the idea of a risk assessment framework, including current knowledge of dose–response relationships; the role of indoor air movement; the various approaches to sampling for biological agents; and the technologies available for decontamination. All of those issues would be important for decision makers to consider in the event a facility requires decontamination.

Based on its analysis of the issue areas listed above, the committee made 26 recommendations. Those described in this Executive Summary are organized into four areas: risk assessment, health, sampling and decontamination standards, and decision making.

RISK ASSESSMENT

Quantitative microbial risk assessment, a discipline developed over the past 20 years, has been used to inform decision making about microbial hazards in food safety, drinking-water quality, and in hospital isolation rooms. The potential variations in agents of the same species and among potential human hosts (immune status) strongly suggest that the limited information currently available should be interpreted cautiously. Although the nonthreshold model implies that there is no amount below which an agent poses zero risk, it indicates that the probability of infection is extremely low. A threshold model, in contrast, implies a definitive threshold below which no infection would occur. Therefore, nonthreshold dose–response models offer a more cautious approach that is appropriate for describing the human response to exposure to a diversity of infectious agents by ingestion, inhalation, and other routes. Full characterization (including screening for known threat agents, genetically modified agents, and emerging-threat organisms) of a suspected biological pathogen is required for proper analysis and to inform decision making. Identification and characterization of the properties of an organism, and the amount and extent of its concentration when cleanup begins, are critical to making decisions about response options (Findings 5-1, 6-1, 6-2, 8-1).

The threat posed by naturally occurring infectious disease is well characterized, and the information available is useful for planning the response to an attack. But weaponized biological agents could pose distinct threats, especially when it comes to decontamination. Dose–response data for most of the pathogens of concern are either incomplete or have not been analyzed critically in the open literature. A complete risk analysis depends on the availability of information about each variable, and the information on agents that might be used in a biological attack is weak for some variables. Because publicly available data on which to base human dose–response assessments for the critical pathogens are minimal, we often must rely on animal data. However, our understanding of interspecies extrapolation from animals to humans remains poor (Findings 2-1, 5-2, 8-2).

The committee recommends that a risk assessment approach be adopted as one component of decision making for determining the adequacy of decontami-

nation efforts after a release or suspected release of a biological contaminant. More data on dose–response relationships are needed to conduct a practical, as opposed to a theoretical, risk analysis for any given biological attack. Available dose–response data for pathogens of concern should be analyzed using nonthreshold dose–response models. Targeted research will help inform decision making on extrapolation for the pathogens of concern. That work might use multiple species of organisms or study animal and human tissues to provide information that is relevant for human exposures. With the increasing difficulty of performing nonhuman primate studies, it will become more important to develop in vitro techniques that can be used to develop dose–response information (Recommendations 5-1, 5-2, 8-1, 8-2).

A characterization system should be developed to inexpensively identify, or partially characterize, all potential threat agents, including genetically modified and emerging-threat agents. Decontamination decisions and plans should account for the natural characteristics of a specific pathogen and for the weaponization characteristics of the agent. Weaponized agents (such as weaponized *B. anthracis*) could vary from crude to sophisticated preparations, formulated to enhance dispersal, increase suspension-in-air time, extend viability, or increase their ability to penetrate a target organism. Given the potential deviation from the natural form, it is not possible to say with complete certainty that a particular agent would pose zero risk at a given exposure. For that reason, the contaminating agent or agents should be characterized before the approach for large-scale remediation is chosen. The remediation approach should ensure adequate destruction or removal of the amount of the agent present at the start of the procedure (Recommendations 2-1, 6-1, 6-2).

HEALTH

People and microorganisms cohabit the world; sometimes their interactions result in human disease. Where people face a greater risk of exposure to pathogens (for example, in laboratories or hospitals), biological safety policies protect against human disease. Decontamination is not a discreet activity, but it is part of a larger set of controls over dangerous microorganisms and their potential to affect health. The earlier contamination is detected the easier it will be to restrict the area of contamination and the number of people exposed. Different monitoring systems—environmental (Biowatch) and medical (syndromic surveillance)—have been put in place with the hope of obtaining the earliest indicator regarding the release of a biological agent. Some type of postevent medical monitoring of the health of people exposed to a contaminant is critical to ensuring confidence in a facility's safety. The purpose and outcome of medical monitoring should be made transparent to affected parties. Because of different objectives for law enforcement agencies and public health agencies, data from the sites contaminated in 2001 were not shared with all relevant parties. Lack of data sharing can

compromise human health in the aftermath of a biological attack (Findings 3-3, 4-2, 6-3).

Existing environmental monitoring systems and syndromic surveillance systems should be evaluated for the ability to provide information that can be used cost effectively to detect and limit the spread of dangerous biological agents. Such programs should be able to detect an agent or to identify unusual clusters of symptoms or disease within a period that ensures the earliest possible public health intervention. If the systems prove effective and affordable, they might be deployed at public facilities that are likely to be targets of an attack or whose removal from service because of contamination would produce catastrophic economic effects. Those systems also could be useful for postevent monitoring. Planning for future incidents should consider mechanisms for establishing a centralized and sustained effort to track the health of people who are exposed, or potentially exposed, to pathogens. Such a program should be evaluated for effectiveness and practicality. Agencies and organizations entrusted with data relevant to public health should make every effort to share the information. To achieve the primary goal of protecting public health and safety, federal agencies should prepare memoranda of understanding to increase cooperation and decrease anxiety (Recommendations 3-3, 4-2, and 6-3).

SAMPLING AND DECONTAMINATION STANDARDS

Biological agents can spread beyond their point of initial release in air-handling systems, by the reaerosolization of contaminants from floors and other surfaces as a result of foot traffic or air currents, through adhesion to people or their clothing, and by transmission from one person to another. The result could be widespread dispersal of biological contaminants within a building, into transportation and transit vehicles, and into homes or other sites. Indoor air-handling systems can redistribute biological agents by carrying airborne contaminants throughout buildings and then outdoors. If appropriate actions are taken, however, air-handling systems also can be used to confine contaminants and reduce the effects of contamination. General guidance from the Centers for Disease Control and Prevention (CDC) directs sampling of *B. anthracis* spores, but there is no official guidance for the collection of vegetative *B. anthracis*, plague bacteria, or smallpox virions. Different threat substances require different sampling protocols. The wide variety of collection approaches currently in use results in widely varying efficiencies, which impede quantification of the extent of initial contamination. Adequate training of decontamination teams is essential for effective remediation and validation. The federal sterilization "metric" of using test strips to verify a "6-logarithm kill" (the reduction of the amount of live contaminant by 6 orders of magnitude) was used as a standard for the remediation of the Hart Senate Office Building in Washington, D.C. However, the amount of contaminant present before decontamination can be many orders of magnitude higher:

One gram of dried *B. anthracis* can produce 10^{11} to 10^{12} active spores. The current standard could leave large amounts of viable organisms (Findings 7-1, 7-2, 9-1, 9-3, 10-3, 10-4).

In the aftermath of an attack, an extensive survey should be done to determine the extent to which biological contamination has spread. Building operators should act now to gain a thorough understanding of air flow under normal operating conditions and the potential adverse or beneficial consequences of a shutdown for the spread of airborne contaminants. Appropriate actions therefore could be taken to minimize the dispersal of contaminants once a release has been identified.

Sampling protocols must be appropriate to the threat. *B. anthracis* sampling should follow published guidance from CDC, including protocols published by the National Institute for Occupational Safety and Health. With input from the Department of Defense, CDC and the American Society for Microbiology should develop sampling and analysis guidelines for the other threat agents. Sampling and analysis methods must be standardized and incorporated into a general sampling plan. Research should be conducted to assess the efficiency of sampling collection and analysis procedures for each type of biological threat substance. Unless the sampling efficiency is known, the amount of contaminant present when cleanup begins cannot be estimated with confidence. A general sampling plan should result from consensus among facility stakeholders, medical and public health personnel, environmental experts, decontamination technologists, laboratory analysts, and worker safety representatives. It should encompass three phases: (1) confirmation and contamination baseline, (2) assessment and characterization, and (3) decontamination effectiveness. The Environmental Protection Agency (EPA) and CDC should establish standards for remediation and validation of contaminated buildings and evaluate current and emerging decontamination techniques to determine efficiencies (Recommendations 7-1, 7-2, 9-1, 9-3, 10-3, 10-4).

DECISION MAKING

Risk is a complex issue, and willingness to accept risk varies among people and circumstances. There are divergent ideas about how much responsibility the government or the owners and operators of public facilities and lands should take to limit public exposure to risk. Those issues have been addressed in various situations, and many policy-making lessons can be learned, for example, from Superfund[1] and the Department of Energy cleanup experiences. But if safety-related standards and protocols are devised behind closed doors, without the

[1]Superfund is the commonly used name for the Comprehensive Environmental Response, Contamination and Liability Act, which authorizes EPA to locate, investigate, and clean up hazardous waste sites.

advice or consent of affected and interested parties, those standards are likely to be questioned or rejected outright.

Lack of transparency for policy decisions that directly affect public health—even in the context of a proclaimed national security interest—can severely erode public confidence. Initiating a planning procedure that involves relevant stakeholders before an event occurs would expedite decontamination and improve the acceptability of decisions made during and after decontamination. Effective response to and recovery from a biological attack requires expertise and input from scientists, building engineers, and stakeholders. Response and recovery alike can be accomplished promptly if there is planning that involves all stakeholders and those with appropriate scientific expertise. Although building owners and managers could begin the planning that involves the building structures and operations, technical and scientific planning involves expertise that is scattered across government agencies. In the event of an actual biological attack, the availability of a soundly drawn plan will certainly hasten the reopening of a facility (Findings 3-1, 3-2, 11-1, 12-2).

Authorities who contemplate how to respond to biological attacks should base their plans on lessons from experiences with decontamination in the broadest sense; they should not consider their charge a completely novel task. Affected parties should be involved in risk management decision making and should participate in technical discussions. Planning should identify those interested parties, form them into a working group, and have them interact regularly in anticipation of coming together to guide an actual recovery effort. The view that a facility is once again "safe" for use will be accepted by the interested parties only if they have had an active, meaningful role in reaching that conclusion (Recommendations 3-1, 3-2).

Building owners and managers should begin to plan immediately. The committee recommends that the National Response Plan (specifically the Biological Incident Annex) or some other suitable federal document be expanded to provide more scientific and technical information on biological weapons, decontamination, sampling and surveying, and epidemiology. The document should describe how a team would operate to collect information pertinent to a response to and recovery from a biological attack. That document also should identify who would be responsible for convening the team. The committee recognizes that formation of such a team might take time, and it therefore outlines the following immediate, short-term, and long-term goals for building managers and the government to consider.

Immediate Goal

Building managers and owners should convene an Operations Working Group that includes representatives of all relevant stakeholder groups to devise a biological attack response and recovery plan. Because the group would not have

all the necessary scientific and technical expertise, it should identify the appropriate government agencies and officials to be contacted in the event of an attack.

Short-Term Goal

The government should identify a group with the appropriate technical and scientific expertise to assist building owners and managers in the event of a biological attack. That group should work with the Operations Working Group to devise the best courses of action for response and recovery.

Long-Term Goal

The federal government should devise a mechanism for keeping government and other interested parties abreast of developments and new technology in surveillance, sampling, and decontamination and revise the standards and policies for decontamination iteratively. The mechanism should ensure that building managers and owners are kept informed (Recommendation 11-1).

REFERENCES

Lane, C.L., and A.S. Fauci. 2001. Bioterrorism on the home front, a new challenge for American medicine. Journal of the American Medical Association 286: 2595-2596.

1

Introduction

2001 ATTACKS AND CLEANUP

Although the anthrax attacks of 2001 did not cause catastrophic morbidity or mortality—5 people died and more than 20 were infected—those incidents resulted in considerable disruption. They had enormous economic and social consequences for the nation. The "anthrax letters" contaminated postal facilities, offices, and residences that required extensive and expensive decontamination. In addition to the economic cost, the attacks caused anxiety and contributed to a nationwide sense of vulnerability: According to one national poll (Blendon et al., 2001), in late November 2001, a third of the U.S. population took precautions in handling mail.

Several groups have noted the dearth of information to guide decontamination efforts. In the wake of the 2001 attacks, the National Academies undertook an effort to define a roadmap for actions that resulted in *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (2002). Summarizing information on the state of the art for rendering facilities and the larger environment safe after a biological attack, that report concluded that more information is needed about dose–response relationships, cleanup criteria, and effective decontamination (Box 1-1).

Before the anthrax attacks, the Working Group on Civilian Biodefense had made several recommendations for medical and public health management after exposure to the highest priority biological weapons (Arnon et al., 2001; Borio et al., 2002; Dennis et al., 2001; Henderson et al., 1999; Inglesby et al., 1999, 2000). The working group is an expert panel convened by the former Center for Civilian Biodefense Strategies at the Bloomberg School of Public Health at Johns Hopkins

BOX 1-1
Development of Decontamination Protocols

Making the Nation Safer (2002) illustrates that much of the information required to quantify the cleanup required to safeguard public health needs in the event of a bioterrorist attack is lacking. Research should be done to fill the knowledge gaps and develop decontamination protocols (pp. 94–95):

At present there are few data on which to base decontamination procedures, particularly for biological agents. A review of the literature shows that dose–response information is often lacking or controversial, and that regulatory limits or other industrial health guidelines (which could be used to help establish the maximum concentrations of such agents for declaring a "decontaminated" environment) are generally unavailable or not applicable to public settings (Raber et al., 2001). Moreover, the correct means for identifying the presence of many biological agents are not known, nor is the significance of the presence of biological agents in the natural environment (e.g., anthrax spores are found in the soil in some parts of the United States). Research is therefore needed to determine what level of cleanup will be required to meet public health needs in the aftermath of a bioterrorist attack.

Although the lack of dose information, cleanup criteria, and decontamination protocols presents challenges to effective planning, several decontamination approaches are available. Such approaches should be combined with risk-informed decision making to establish reasonable cleanup goals for the protection of health, property, and resources. Efforts in risk assessment should determine what constitutes a safety hazard and whether decontamination is necessary. Modeling exercises are needed that take into consideration the characteristics of a particular pathogen, public perceptions of the risk that the pathogen poses to their health, the level of public acceptance of recommendations based on scientific criteria, levels of political support, time constraints in responding to the threat posed by a pathogen, and economic concerns (Raber et al., 2001).

University in Baltimore, Maryland. That group issued consensus statements on medical and public health guidelines for diagnosing, treating, and managing health effects that could result from future bioterrorist attacks. The position papers addressed some aspects of decontamination, but they did not consider the amount of cleanup necessary to meet the needs of interested and affected parties. In the absence of technically sound guidance, it is difficult to define what constitutes an adequate extent of cleanup from a public health perspective. Recent experience has shown that extensive and repeated cleanup, in the context of uncertain risk, could incur substantial costs without additional benefit.

Even though thousands of people have reentered the buildings that were decontaminated, 3 years after the attacks we still face the same fundamental

question: "How clean is safe?" If we experience another bioterrorist attack, we should be prepared to ensure the safety of facilities in a more timely manner.

CONTEXT OF THE STUDY AND CHARGE TO THE COMMITTEE

This study was sponsored by the Department of Homeland Security as part of a larger project, run by the Lawrence Livermore and Sandia National Laboratories, called the Restoration and Domestic Demonstration and Application Program. That program focuses on developing procedures, plans, and technologies for the rapid, safe restoration of transportation nodes after a biological attack. The primary focus of the demonstration project is major airports, which were chosen for the scenario because an attack at an airport, in addition to the likely health effects, would cause major transportation disruption and would have serious economic consequences. Effective and efficient decontamination and restoration of such a facility would be imperative to minimize social and economic harm.

At the initial meeting, the Committee on Standards and Policies for Decontaminating Public Facilities Affected by Exposure to Harmful Biological Agents heard from representatives of Lawrence Livermore National Laboratory. Representatives from the sponsoring agency explained that additional information was needed for the demonstration project. Because of the specific request from the sponsor, this study is not a review of all issues that would need to be considered in the aftermath of a biological attack. Rather, it examines relevant issues and the steps that would lead to a decision to reoccupy a decontaminated building. For clarity, some of the issues that are the focus of the study are listed here:

- The study focuses on large buildings, such as airports, and does not consider outdoor contamination. (Two wide-area restoration projects are under way by other groups, the Homeland Security Institute and Clean Earth Technologies.)
- The committee was asked to examine the final stages of cleanup. Therefore, the report does not address in any detail the risk that such an attack would occur, emergency response to an attack, decisions about whether to initiate cleanup or raze a facility, issues related to the appropriate allocation of resources for research or response, or broader public health issues related to transmissible diseases. The report does not recommend decontamination methods for given circumstances, although some techniques are discussed to provide information to those who would make final cleanup decisions.
- The committee was charged with laying the technical foundations for establishing standards and policies. Where the committee determined that social science considerations would be important in formulating such standards and policies, those issues are addressed. However, the committee was not specifically assigned topics such as education of participants in the decision-making process or communicating with the public about risk; those topics are not covered in detail here.

The committee was specifically asked to consider a scenario in which decontamination of a facility approaches completion. It was directed to assess the criteria that must be met for a cleanup to be declared successful, thus allowing the reoccupation. This committee has therefore reviewed the factors that influence decision making and that lay the foundation for establishing standards and policies for relevant aspects of biological decontamination. It was asked to examine four specific topics: infectious dose, quantitative risk assessment, natural and residual contamination, and past cleanup efforts (see Appendix A for the complete Statement of Task). In responding, the committee considered the tasks and reorganized them into the five groups described here.

Infectious Dose

The 2001 anthrax attacks called into question the state of knowledge on infectious dose for *Bacillus anthracis*. The term infectious dose often has been used to denote the number of organisms that are believed necessary to overwhelm the host defense mechanism and establish an infection that can lead to disease. The committee was asked to evaluate the current understanding of infectious dose for warfare-related biological agents such as *B. anthracis* and to assess the validity and uncertainty associated with knowledge of infectious doses. The report was to discuss relevant representative organisms among the infectious–nontransmissible and infectious–transmissible gram positive and gram negative bacteria and viral pathogen classes to identify areas in which additional research is required.

Natural Background

The committee was asked to examine what is known about natural environmental background concentrations of various microorganisms and their potential effects on surrounding populations. People tolerate some exposure to microbial pathogens in the environment and those concentrations must be considered in assessing risk. Relevant information on natural environmental background contamination that causes few or no human health effects was to be evaluated.

Quantitative Risk Assessment

The committee was asked to examine quantitative risk assessment models (Box 1-2 lists various definitions) and evaluates their suitability for application to the safety of decontaminated public transportation facilities. The committee was asked to develop the conceptual components of the four risk assessment steps (hazard identification, exposure assessment, dose–response assessment, and risk characterization) for the organism types considered in the study.

- Hazard identification identifies aspects of the organisms (such as infectivity) and situations (form of biological hazard, for example, fine aerosol) that represent threats to human health.
- Exposure assessment estimates the dose encountered, considering sources (including environmental background), spatial distribution, duration of exposure, and pathway (ingestion, inhalation, dermal).
- Dose–response assessment uses available data to relate dose to adverse health response. The committee examined the existing dose–response models for each selected organism and attempted to determine whether there is a threshold dose below which there is no effect (infectious dose zero, ID0).
- Risk characterization combines exposure and dose–response assessment to quantify, for a defined population (considering age, sex, ethnicity, and overall health), the risks predicted to result from the exposure. The committee was asked to test the models for relevant representative organisms to assess the potential risk associated with identified options for specific amounts of cleanup. The committee was to determine the cleanup associated with a range of infectious doses—1:1,000,000 or ID 10^{-6} to 1:10,000 or ID 10^{-4}. An infectious dose of 1:1,000,000, also known as ID 10^{-6}, describes the dose that would result in 1 infection in 1 million people. It was to describe how those data could be used in establishing acceptable measures of decontamination for selected organisms.

Past Cleanup Efforts

The committee was asked to review the efforts to clean up *B. anthracis* in 2001 to more completely identify the implications of exposure and dose for infectivity and immunity. The review was to examine federal and private efforts, including the cleanup of the American Media, Inc., building in Boca Raton, Florida.

Residual Contamination

The committee was asked to address whether some biological agents degrade rapidly enough that decontamination is not necessary. Part of that charge was an in-depth assessment of representative organisms that would require decontamination and a discussion of the time factor for degradation in various environments (with and without treatment) to help determine decontamination approaches and requirements. An additional component for the committee to consider was the means of estimating the exposure that could arise from residual contamination at various locations in a facility (inside air ducts or on equipment). The committee was asked to evaluate various approaches, including monitoring methods and performance evaluation targets, and describe how the information could be used to assist in determining safe concentrations of residual contamina-

BOX 1-2
Definitions of Risk Assessment

"Risk Assessment is the process of establishing information regarding acceptable levels of a *risk* and/or levels of risk for an individual, group, society, or the *environment*." (Risk Assessment Information Glossary, U.S. Department of Energy, Office of Environmental Management, Oak Ridge Operations Office. Online: *http://risk.lsd.ornl.gov/homepage/glossary.shtml#R)*

"An ecological risk assessment evaluates the potential adverse effects that human activities have on the plants and animals that make up ecosystems. The risk assessment process provides a way to develop, organize and present scientific information so that it is relevant to environmental decisions. When conducted for a particular place such as a watershed, the ecological risk assessment process can be used to identify vulnerable and valued resources, prioritize data collection activity, and link human activities with their potential effects. Risk assessments can also provide a focal point for cooperation among local communities and state and federal government agencies. Risk assessment results provide a basis for comparing different management options, enabling decision makers and the public to make better informed decisions about the management of ecological resources." (EPA National Center for Environmental Assessment. Online: *http://cfpub.epa.gov/ncea/cfm/ecologic.cfm*)

"The process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment." (Glossary from the Society for Risk Analysis. Online: *http://www.sra.org/resources_glossary_p-r.php*)

"Risk assessment is essential for setting occupational safety and health priorities and for demonstrating health impairment when promulgating occupational standards. Risk assessment has been most often applied in assessing the risk of carcinogens, often with animal bioassay data. However, evaluation of these procedures has been limited, and questions abound as to whether the resulting risk estimates are reasonable. Risk assessment for noncarcinogens, particularly quantitative approaches, is even less well developed. Improved methods are needed for using animal bioassay data and human health effects data to generate risk estimates for cancer and noncancer effects and injury." (National Occupational Research Agenda of CDC. Online: *http://www.cdc.gov/niosh/nrram.html*)

"Risk assessment is a process in which hazard, exposure, and dose–response information are evaluated. These evaluations determine whether an exposed population is at greater-than-expected risk of disease (cancer or noncancer endpoints) or injury. Once this is established, the magnitude and nature of the increased risk can be explored further, using either qualitative or quantitative approaches. Qualitative risk assessments are generally descriptive and indicate that disease or injury is likely or unlikely under specified conditions of exposure. On the other hand, quantitative risk assessments provide a numerical estimation of risk based on mathematical modeling. For example, under given specific exposure conditions, it is expected that one person per 1,000 would develop a disease or injury.

Quantitative risk assessments require (1) data providing as much detail as possible on exposures relevant to the adverse health outcomes of interest, and (2) development of a mathematical model describing that exposure–response relationship. Risk assessments based on experimental animal and molecular biologic data provide detailed information on the exposure–response relationships. However, there is often substantial concern about the validity of using risk assessments based on susceptible animal species tested at high constant doses to estimate the risks to workers who may have much lower and more variable workplace exposures. Risk assessments based on epidemiologic, population-based studies may have real-world relevance to workers, but they generally suffer from a number of limitations. These include potential confounding by risk factors for exposures other than the exposure of interest, variability in workplace exposures for any particular substance or mixture of exposures, individual variability in health response, and detection of statistically significant changes in adverse health outcomes. The integration of mechanistic data, human data, toxicity testing data, and biomathematics can be useful for developing methods that strengthen the scientific foundation on which risk assessments are based.

The risk assessment process has become increasingly formal and sophisticated over the past decade. There are many who support a greatly expanded and even more formal role for risk assessment in establishing national priorities and providing a justification for regulatory actions by Federal agencies. In occupational safety and health regulation, that process began when the U.S. Supreme Court ruled in the 'benzene decision' [Industrial Union Department v. American Petroleum Institute, 448 U.S. 607 (1980)] that the Occupational Safety and Health Administration (OSHA) could not issue a standard without demonstrating a significant risk of material health impairment. The ruling allowed (but did not demand) that numerical criteria could be used to determine whether a risk is 'significant.' As a result of that Supreme Court ruling, risk assessment became standard practice in OSHA rulemaking for health standards, and quantitative risk assessments are preferred whenever data, modeling techniques, and biological understanding are adequate to support their development.

"Research to improve risk assessment methods is needed from a wide range of scientific disciplines to provide more reliable methods for estimating the risk of adverse effects related to work. Substantial controversy surrounds currently available cancer risk assessment models, and models for noncancer effects are even less well developed. Lagging even more are methods for assessment of safety risks. Innovative and practical new approaches to modeling are needed. In addition, research needs to be directed to the following areas: designing epidemiologic and toxicologic studies that provide detailed and accurate exposure–response relationship data for specific hazards; generating more data on which to base models that include intake distribution, metabolism, and elimination; developing biologic markers for exposures and effects; and utilizing existing occupational safety and health data to ensure that human observations complement and validate risk estimates derived from animal data. Research efforts should also evaluate how risk assessment estimates are used in risk management, communicated to the public, and perceived by workers and employers." (National Institute for Occupational Safety and Health, National Occupational Research Agenda, Risk Assessment Methods, Additional Information. Online: *http://www2a.cdc.gov/nora/NaddinfoRisk.html*)

tion. The committee was given the option of considering pathogens that typically are nonlethal, but whose virulence can result in the incapacitation of large numbers of people, thereby causing disruption, fear, and anxiety.

CONTENT AND STRUCTURE

In the context of an incomplete scientific record, controversy has arisen over the response to the anthrax letter attacks and the extent to which the United States is prepared for the possibility of future terrorist attacks. This report provides a decision-making framework with which to approach the safe return of the public to a building that has been decontaminated after a biological attack.

The report consists of three parts. Part I provides background information. This chapter describes the purpose and gives an overview of the report. Chapter 2 discusses the complex nature of the relationship between humans and microorganisms and the use of microorganisms as biological weapons. It also reviews microbiological, clinical, and epidemiological features of the agents of greatest concern to national security and public health policy. Chapter 3 reviews U.S. history and policy related to the remediation of microbiological, chemical, and radiological contamination. Although the case studies described in Chapter 3 are not directly related to terrorist attacks, many of the lessons learned in managing contamination are relevant. Chapter 4 chronicles the public health consequences of the release of a weaponized[1] form of anthrax in the fall of 2001 and the social, political, and practical challenges posed by cleanup efforts.

Part II surveys risk-based approaches for cleanup after an attack and describes the challenges of using those approaches and the technical protocols that could be applied. Part II contains information that is pertinent to decision making on safe reoccupation. It is organized into five separate chapters to aid readers who seek specific technical information. Chapter 5 evaluates the applicability of a risk assessment and management framework. Chapters 6, 7, and 8 consider in significant detail current limitations to identifying microbial contaminants, modeling population exposure, and analyzing dose–response relationships. Chapters 9 and 10 review sampling technologies and strategies and describe practices and principles for decontamination based on current knowledge and experience.

Drawing from the biological information and the social context of Part I and the technical context of Part II, Chapter 11 sketches a generic framework for making decisions about safe return to a building affected by a biological attack. Chapter 12 describes an ideal, proactive strategy for quickly and safely returning an airport and other public buildings to use.

[1]Weaponized microorganisms are processed to enhance stability, infectivity, environmental half-life, or ease of dissemination.

Because of the relative lack of data on other potential biological weapons, the report primarily uses weaponized *B. anthracis* as its example. No claim is made that experiences are directly transferable to other pathogens, but in many cases they provide the best information available on the issues that must be considered for making decisions about decontamination.

CONCLUSION

The 2001 anthrax attacks and cleanups brought into sharp relief the knowledge that the United States lacked the necessary information to make scientifically sound, socially acceptable decisions about when buildings might be safely reoccupied after a harmful biological exposure. Although all the scientific and technical information related to harmful biological agents—for exposure, decontamination, and subsequent reoccupation—might not be available, building managers and decision makers are still responsible for decontaminating an affected facility and ensuring the safety of its occupants. Decontamination policies and practices can be developed now despite the knowledge gaps, and such policies and guidelines can be improved using an iterative process that builds on new research findings.

The committee was asked to assess risk for various amounts of residual contamination. It concludes that current data are insufficient to determine correlations. More research on dose–response relationships would allow scientists to narrow the uncertainty associated with the risks. However, even with improved correlations, the decision to reopen a facility is a complex issue that involves social decisions about what constitutes "safe." This report provides a framework for thinking about issues that must be considered in the decision to reopen a facility after an attack. The committee hopes that it serves as a resource to help decision makers better understand the relevant concerns.

In addressing its charge, the committee reached specific conclusions for each of the areas described above: infectious dose, natural background, risk assessment, past cleanup efforts, and residual contamination.

Infectious Dose

The 2001 anthrax attacks called into question the state of knowledge on infectious dose for *B. anthracis*. The committee concluded that infectious doses for harmful biological agents that can be used as weapons cannot be determined with confidence because the infectivity and virulence of harmful agents can vary by strain, within species, and by type of preparation for weapons. Currently available data on dose–response relationships are not as detailed as demanded by modern scientific standards, in most cases covering only exposure in young healthy adults.

Natural Background

The committee acknowledges that natural environmental background concentrations of various microorganisms have been assessed in some places and that most people tolerate exposure without adverse effects. One hypothesis is that those people might have developed immunity through exposure. The concept of natural background might not apply to acts of bioterrorism in indoor public facilities because it is unlikely that a detectable natural background concentration of weaponized agents, such as those in the Centers for Disease Control and Prevention's (CDC's) highest risk group, Category A,[2] are present in indoor public facilities. Moreover, the agent used in an act of bioterrorism could deviate from its natural form, depending on whether the weaponization process alters its characteristics.

Quantitative Risk Assessment

Quantitative risk assessment models often are used to evaluate complex situations. The models traditionally have four steps—hazard identification, exposure assessment, dose–response assessment, and risk characterization. Various definitions of risk assessment are presented in Box 1-2. A complete risk assessment of the most thorough type described there would exceed the charge to this committee. However, aspects of such models could be useful for assessing risks of exposure to harmful biological agents after cleanup, even though the essential data to support thorough analysis by quantitative risk assessment are currently lacking for some agents that might be used as biological weapons. An example of how such data would be used to evaluate risk in the very last stages of a cleanup is presented in Chapter 8 and Appendix E.

Projects in the area of risk assessment for biological hazards, such as those of the U.S. Army Center for Health Promotion and Disease Prevention, and the Department of Homeland Security's Biological Threat Information Center, which is part of the National Biodefense Analysis and Countermeasures Center, should be noted. They could provide information for use in the future to allow for more precise calculations of risk.

Past Cleanup Efforts

The cleanup of *B. anthracis* following the events of 2001 provides insights about the approaches that should be used in the event of a future attack.

[2]The CDC's categories are discussed in Chapter 2.

Residual Contamination

Some biological agents in their natural forms would likely degrade rapidly enough that extensive cleanup would not be necessary after an initial decontamination. However, a preliminary analysis of the agent used as a weapon might not reveal alterations that could affect its viability. Therefore, a full characterization of the agent would be necessary to evaluate the effect of genetic or physical modifications on its viability before an informed decision could be made about cleanup. After cleanup, continuous medical monitoring might be useful to ensure the safety of those who would use the decontaminated space.

The committee concluded that there is insufficient information on which to base "safe" numbers of residual biological agents for a decontaminated facility. Further research could provide additional information on infectious dose that would decrease the uncertainties and make a quantitative approach more useful. However, the risk different people or groups of people are willing to tolerate will always vary. Therefore, the issues related to decision making raised in this report will continue to be relevant. The report considers lessons from the response to the 2001 anthrax attacks and from other situations involving chemical or radiological decontamination; the idea of a risk assessment framework, including current knowledge of dose–response relationships; the role of indoor air movement; the various approaches to sampling for biological agents; and the technologies available for decontamination. All of those issues would be important for decision makers to consider in the event a facility requires decontamination.

Based on its analysis of the issue areas listed above, the committee made 26 recommendations.

REFERENCES

Arnon, S.S., R. Schechter, T.V. Inglesby, D.A. Henderson, J.G. Bartlett, M.S. Ascher, E.M. Eitzen, Jr., A.D. Fine, J. Hauer, M. Layton, S. Lillibridge, M.T. Osterholm, T. O'Toole, G. Parker, T.M. Perl, P.K. Russell, D.L. Swerdlow, and K. Tonat. 2001. Botulinum toxin as a biological weapon: medical and public health management. Journal of the American Medical Association 285(8): 1059-1070.

Blendon, R.J., J.M. Benson, C.M. DesRoches, and M.J. Herrmann. 2001. Harvard School of Public Health/Robert Wood Johnson Foundation survey project on Americans' response to biological terrorism, study 2: National and three metropolitan areas affected by anthrax, November 29-December 3, 2001. [Online]. Available at: http://www.hsph.harvard.edu/press/releases/blendon/report2.pdf (accessed 7 January, 2002).

Borio, L., T.V. Inglesby, C.J. Peters, A.L. Schmaljohn, J.M. Hughes, P.B. Jahrling, T. Ksiazek, K.M. Johnson, A. Meyerhoff, T. O'Toole, M.S. Ascher, J. Bartlett, J.G. Breman, E.M. Eitzen, Jr., M. Hamburg, J. Hauer, D.A. Henderson, R.T. Johnson, G. Kwik, M. Layton, S. Lillibridge, G.J. Nabel, M.T. Osterholm, T.M. Perl, P. Russell, and K. Tonat. 2002. Hemorrhagic fever viruses as biological weapons: medical and public health management. Journal of the American Medical Association 287(18): 2391-2405.

Dennis, D.T., T.V. Inglesby, D.A. Henderson, J.G. Bartlett, M.S. Ascher, E.M. Eitzen, Jr., A.D. Fine, A.M. Friedlander, J. Hauer, M. Layton, S.R. Lillibridge, J.E. McDade, M.T. Osterholm, T. O'Toole, G. Parker, T.M. Perl, P.K. Russell, and K. Tonat. 2001. Tularemia as a biological weapon: medical and public health management. Journal of the American Medical Association 285(21): 2763-2773.

Henderson, D.A., T.V. Inglesby, J.G. Bartlett, M.S. Ascher, E. Eitzen, P.B. Jahrling, J. Hauer, M. Layton, J. McDade, M.T. Osterholm, T. O'Toole, O. Parker, T. Perl, P.K. Russell, and K. Tonat. 1999. Smallpox as a biological weapon: medical and public health management. Journal of the American Medical Association 281: 2127-2137.

Inglesby, T.V., D.A. Henderson, J.G. Bartlett, M.S. Ascher, E. Eitzen, A.M. Friedlander, J. Hauer, J. McDade, M.T. Osterholm, T. O'Toole, G. Parker, T.M. Perl, P.K. Russell, and K. Tonat. 1999. Anthrax as a biological weapon: medical and public health management. Journal of American Medical Association 281:1735-1963.

Inglesby, T.V., D.T. Dennis, D.A. Henderson, J.G. Bartlett, M.S. Ascher, E. Eitzen, A.D. Fine, A.M. Friedlander, J. Hauer, J.F. Koerner, M. Layton, J. McDade, M.T. Osterholm, T. O'Toole, G. Parker, T.M. Perl, P.K. Russell, M. Schoch-Spana, and K. Tonat. 2000. Plague as a biological weapon. Medical and public health management. Journal of American Medical Association 283: 2281-2290.

NRC (National Research Council). 2002. Making the Nation Safer: The Role of Science and Technology in Countering Terrorism. Washington, DC: National Academy Press.

Raber, E., A. Jin, K. Noonan, R. McGuire, and R.D. Kirvel. 2001. Decontamination issues for chemical and biological warfare agents: how clean is clean enough? International Journal of Environmental Health Research 11: 128-148.

2

Infectious Disease Threats

This chapter examines the differences between naturally occurring infectious disease threats and threats posed by biological weapons. There is considerable knowledge and experience in diagnosing and treating naturally occurring infectious diseases in the United States and around the world. Bioterrorism poses specific and complex problems that do not exist within the context of natural infectious disease. For example, the concentration of a disease agent used in a bioterrorist attack is likely to be much higher than is the concentration found in any natural setting. Moreover, if a "weapons-grade" agent (for example, a highly refined preparation of *Bacillus anthracis* spores designed to disperse readily in the environment) is used, the remediation of a building will present special epidemiological, technological, operational, and social considerations, as this and later chapters illustrate.

ABILITY OF MICROORGANISMS TO INFECT PEOPLE

The human race is continually exposed to microorganisms. Our water, soil, and air are laden with microorganisms that adapt continuously to the environments; a small proportion of those organisms cause infectious diseases. Within buildings, microorganisms can circulate through the air, reaching locations distant from the source. In hospitals, for example, medical staff, clinical staff, patients, and visitors are continuously exposed to microorganisms, as they are in natural settings. Fortunately, humans have evolved complex systems to defend against pathogenic or disease-producing microorganisms that often can prevent infection from becoming established.

In some circumstances, precautions can be taken when it is known that defenses are compromised—for example, during surgical procedures and when people are likely to be exposed to particularly dangerous pathogens. The choice of precautions depends on the potential route of exposure and infection, and it can range from wearing a mask in an area where airborne pathogens could be a high threat; to wearing gloves and protective clothing to avoid direct transmission of pathogens; to isolating patients in clean rooms where air is filtered, food and water sterilized, surfaces disinfected, and anyone who enters is masked and gowned to avoid exposure or transmission.

Many biological agents considered to be the most serious disease threats enter the body via the respiratory system. In some cases, only direct environmental exposure would cause disease (there is no person-to-person transmission). For example, *B. anthracis* spores can be inhaled, ingested with contaminated food or water, or contacted by the skin on contaminated surfaces. In many cases, infected people pose no risk to others. In other cases—such as smallpox and plague—the risk of inhalation from intentionally contaminated environments is complicated with the risk of interpersonal transmission. Successful introduction of an agent via the airway is possible under specific conditions. The optimal size for a particle that contains the infectious microorganism is about 5 micrometers (μm) for efficient penetration to the lower airway (within the lung). However, smaller or larger (up to 12 μm) particles can cause disease by entering the upper respiratory tract (Davis, CUBRC, Inc., 2004 personal communication).

To cause disease, in most cases, the pathogenic agent must enter and multiply in the cells of the host's body. In the laboratory, each intact and complete bacterial or viral particle has the ability to multiply. However, virulence and infectivity can vary within a bacterial or viral population and among different strains of the same species. In the host, successful infection, multiplication, and resulting disease can be a rare event. Normally, host defenses are overcome only when challenged simultaneously by many of the same type of pathogenic microorganism; the number needed to cause disease is called the *infectious dose*. If the agent begins to multiply in an infected cell, the cell will be altered to become a potential target of the immune system. The likelihood that an infection will lead to disease depends on how many microorganisms infect the host initially, the nature of the agent (some are naturally better able to overcome the host's defenses), and the state of the host's immune system, which varies within a population. For example, young children and elderly people often have weaker immune systems than healthy adults do. In addition, there is an increasing number of people who are more susceptible than average in the U.S. population because they are immunocompromised, either due to a genetic deficiency, because of a metabolic disease, or as a side effect of therapy for an illness such as cancer.

INFECTIOUS DISEASE AS A WEAPON

The events of September 11, 2001, produced an increased awareness of the United States' vulnerability to acts of terrorism. While the nation was dealing with the aftermath of the 9/11 attacks, an anthrax attack (Amerithrax) occurred, turning the hypothetical threat of bioterrorism into reality (Atlas, 2001, 2002). Although those attacks were not the first instance of bioterrorism in the United States, they made many more Americans aware of and concerned about the threat.

Previous bioterrorism in the United States and elsewhere was not as well publicized and did not produce such widespread public reaction. In 1984, the Rajneesh cult spread *Salmonella typhimurium* on salad bars in The Dalles, Oregon, in an attempt to influence the outcome of an election by making the opposition ill and unable to vote. The resulting illnesses initially were thought to be a case of natural foodborne disease, but later the event was recognized as an act of bioterrorism (Torok et al., 1997). In the early 1990s, the Aum Shinrikyo cult experimented with the release of *B. anthracis* spores and botulinum toxin in Japan before carrying out a chemical agent attack in the Tokyo subway with sarin (Smithson and Levy, 2000; Wheelis, 2003). Biological weapons also have been used in various criminal acts during the past century—for example, the infamous assassination of a Bulgarian emigré in London using ricin and contamination of muffins with *Shigella dysenteriae* at a hospital in Texas (Carus, 2001; Kolavic et al., 1997). There also have been many hoaxes, including many hundreds of letters claiming to contain anthrax sent between 1997 and 2001 to abortion clinics and other organizations (Cole, 2003).

The United States, the Soviet Union, Canada, Great Britain, South Africa, Iraq, Japan, and others have had national biological weapons programs, and there has been limited use of biological weapons in warfare dating back to B.C. 600 (NRC, 2004; Wheelis, 1999a, b). An important current concern regarding bioterrorism is that terrorist groups might recruit scientists and acquire biological weapons material previously associated with national programs. Particular worry is attached to the former Soviet Union, which continued its program after 1972 despite signing the Biological Weapons Convention and agreeing to eliminate its program. The Soviet biological effort was massive: It employed over 50,000 "bioweaponeers" and produced hundreds of tons of weapons (Alibek, 1999; Davis, 1999), and the fate of some of those scientists and materials and the knowledge they produced is not known (Alibek, 1999).

The general properties of many of the more widely known biological threat agents are listed in Table 2-1. That list, adapted from the appendix of the U.S. Army Medical Research Institute of Infectious Disease's (USAMRIID's) *Medical Management of Biological Casualties Handbook* (USAMRIID, 2001), shows that a wide range of agents have been considered for use in military programs.

The term *weaponized agent* is now broadly interpreted to mean a biological

TABLE 2-1 Biological Weapons Characteristics

Disease	Human Transmission	Infective Dose, Aerosol	Incubation Period	Duration of Illness	Lethality[a]	Persistence	Vaccine Efficacy, Aerosol Exposure
Inhalation anthrax	No	8000-50,000 Spores	1-6 Days	3-5 Days; usually fatal if untreated	High	Very stable; spores remain viable for >40 years in soil	2-Dose efficacy against ≤1000 LD_{50}[b] in monkey
Brucellosis	No	10-100 Organisms	5-60 Days (usually 1-2 months)	Weeks to months	<5% Untreated	Very stable	No vaccine
Cholera	Rare	10-500 Organisms	4 Hours-5 days (usually 2-3 days)	≥1 Week	Low with treatment; high without	Unstable in aerosols, fresh water; stable in saltwater	No data on aerosol
Glanders	Low	Assumed low	10-14 Days via aerosol	Death in 7-10 days in septicemic form	>50%	Very stable	No vaccine
Pneumonic plague	High	100-500 Organisms	2-3 Days	1-6 Days (usually fatal)	High unless treated within 12-24 hours	Up to 1 year in soil; 270 days in live tissue	3 Doses, not protective against 118 LD_{50} in monkey
Tularemia	No	10-50 Organisms	2-10 Days (average 3-5)	≥2 Weeks	Moderate if untreated	Months in moist soil, other media	80% Protection against 1-10 LD_{50}
Q Fever	Rare	1-10 Organisms	10-40 Days	2-14 Days	Very low	Months on wood,	94% Protection
Smallpox	High	Assumed low (10-100 organisms)	7-17 days (average 12)	4 Weeks	High to moderate	Very stable	Vaccine protects against large doses in primates

Venezuelan equine encephalitis	Low	10-100 Organisms	2-6 Days	Days to weeks	Low	Relatively unstable	TC 83 vaccine protects against 30-500 LD_{50} in hamster
Viral hemorrhagic fever	Moderate	1-10 Organisms	4-21 Days	Death in 7-16 days	High for Zaire strain; moderate for Sudan	Relatively unstable, depending on agent	No vaccine
Botulism	No	LD_{50} for type A: 0.001 µg/kg[c]	1-5 Days	Death in 24-72 hours; lasts months if not lethal	High, without respiratory support	Weeks in nonmoving water and food	3-Dose efficacy: 100% against 25-250 LD_{50} in primates
Staph enterotoxin B	No	Incapacitation: 0.03 µg/person	3-12 Hours after inhalation	Hours	<1%	Resistant to freezing	No vaccine
Ricin	No	LD_{50} in mice:	18-24 Hours 3-5 mmg/kg[c] for ingestion	Days; death within 10-12 days	High	Stable	No vaccine
T-2 Mycotoxins	No	Moderate	2-4 Hours	Days to months	Moderate	Years at room temperature	No vaccine

[a] Approximate case fatality rate.
[b]LD_{50}, - The amount of toxin or microorganism sufficient to kill 50 percent of a population of animals within a certain time .
[c]µg/kg, micrograms per kilogram body weight.

SOURCE: Adapted from USAMRIID, 2001.

agent that has been processed to enhance its stability, infectivity, or environmental half-life or the ease of its dissemination. The properties and characteristics of biological weapons can vary, depending on formulation. Altered characteristics (such as particle size, electrostatic charge, viability, suspension time in air, particle agglomeration/flocculation rates, and ability to penetrate target organisms) must be considered during decontamination and in decision making about reoccupation of buildings. For example, agents that settle to the floor quickly might require only surface decontamination and could be less likely to disperse widely than are agents that remain suspended in air for a long time. Such characteristics can have serious implications for the need to decontaminate and the processes used.

AGENTS OF CONCERN TO NATIONAL SECURITY AND PUBLIC HEALTH

Several federal agencies have created lists that categorize biological agents, based on the risks those agents pose to the public. Each list is a little different. For example, the U.S. Department of Agriculture lists focus on threats to plants and animals; the U.S. Centers for Disease Control and Prevention (CDC) lists focus on threats to human health. The CDC's Category A list identifies organisms that pose a risk to national security because they can be easily disseminated or transmitted from one person to another. The infections caused by Category A organisms result in high mortality rates and have the potential for major public health consequences. They also could cause social disruption and would require special action for public health preparedness. Category A includes anthrax (*B. anthracis*), plague (*Yersinia pestis*), smallpox (variola major), tularemia (*Francisella tularensis*), viral hemorrhagic fevers (filoviruses such as Ebola and Marburg or arenaviruses such as Lassa or Machupo), and botulism (*Clostridium botulinum* toxin).

CDC's Category B agents are moderately easy to disseminate, result in moderate morbidity rates and low mortality rates, and require specific enhancements of CDC's diagnostic capacity and enhanced disease surveillance. The Category B agents include brucellosis (*Brucella* species), the epsilon toxin of *Clostridium perfringen*, food safety threats (*Salmonella* spp., *Escherichia coli* O157:H7, *Shigella* spp.), glanders (*Burkholderia mallei*), melioidosis (*Burkholderia pseudomallei*), psittacosis (*Chlamydia psittaci*), Q fever (*Coxiella burnetii*), ricin from *Ricinus communis* (castor beans), staphylococcal enterotoxin B, typhus fever (*Rickettsia prowazekii*), viral encephalitides (alphaviruses such as Venezuelan equine encephalitis, Eastern equine encephalitis, Western equine encephalitis), and water safety threats (*Vibrio cholerae*, *Cryptosporidium parvum*).

CDC's third list (Category C) includes pathogens that could be engineered for mass dissemination in the future because of availability, ease of production and dissemination, and potential for high morbidity and mortality rates and major

health consequences. The Category C agents include emerging infectious-disease threats such as Nipah virus and hantavirus.

The CDC categories are based on threats to human health and not on the difficulties each organism might present for decontamination. CDC does offer some guidance on persistence of naturally occurring varieties of disease-causing organisms. For example, it suggests that both variola virus (CDC, 2004a) and *Y. pestis* (CDC, 2004b) become inactive after short periods. The USAMRIID information reproduced in Table 2-1 is based on the perspective of organisms as potential weapons and reveals that even organisms that generally are short lived in the environment can sometimes persist for weeks, months, or years. For example, smallpox can survive over extended periods in scabs and after lyophilization; *Y. pestis* can live for at least a year in soil. The biological agents used in future acts of terrorism in public facilities could be specifically prepared to persist for extended periods. In the former Soviet Union, preparations of both smallpox and plague which were intended for biological warfare were stable for months (Alibek, 1999).

BIOLOGICAL AGENTS CONSIDERED IN THIS REPORT

This report provides guidelines for determining when a facility that has been contaminated with a harmful biological agent is safe for reoccupation. At the first meeting of the Committee on Standards and Policies for Decontaminating Public Facilities Affected by Exposure to Harmful Biological Agents, the study sponsors asked the committee to consider three agents: variola major virus (smallpox), *B. anthracis* (anthrax), and *Y. pestis* (plague). Those agents were chosen because they could be among the most dangerous and because they can be used to exemplify the decontamination requirements for other substances. *B. anthracis* is an endospore-forming bacterium, which makes it especially persistent in the environment. *Y. pestis* does not form endospores and naturally is less persistent in the environment, as are some other non-spore-forming bacteria such as *B. pseudomallei* (glanders), *B. pseudomallei* (melioidosis), and *Brucella* spp. (brucellosis). Smallpox virus was chosen to represent the entire class of viral infectious agents, such as viral hemorrhagic fever viruses and Eastern equine encephalitis virus. Examination of toxins, such as botulinum toxin and ricin, was not included in the charge to the committee, but decontamination of toxin-affected spaces can be similar to the decontamination of areas exposed to harmful chemical agents.

The charge to the committee called for consideration of transmissible and nontransmissible organisms; the agents described above cover both categories. Contagious is a commonly used word but its meaning is not as precise as *transmissible*, so the latter term is used in this report. *Transmissibility* is a term that is accepted among medical and biological weapons experts to have the precise meaning of "able to be passed from person to person."

Anthrax

Anthrax is a zoonotic disease—that is, communicable from animals to humans under natural conditions—that occurs primarily in herbivorous animals. It is caused by infection with *B. anthracis*, a gram-positive endospore-forming rod. *B. anthracis* has three known virulence factors: an antiphagocytic capsule and three proteins—edema factor, lethal factor, and protective antigen. Animals most frequently acquire anthrax by ingesting plant material contaminated with soil that contains *B. anthracis* spores. Humans usually acquire anthrax from the environment or from natural transmission through contact with infected animals or contaminated animal products. Although anthrax is an infectious disease, it is not normally transmissible.

At least 66 people were killed by inhalational anthrax after the accidental release of *B. anthracis* spores from a Soviet military compound in Sverdlovsk in 1979 (Meselson et al., 1994). The attack in 2001, in which weapons-grade preparations of *B. anthracis* spores were sent by mail, resulted in 11 cases of cutaneous anthrax with no fatalities and in 11 cases of inhalational anthrax with 5 deaths (Atlas, 2001).

Human infection with *B. anthracis* can result from inhalation of spores (inhalational anthrax), by inoculation of spores into the skin (cutaneous anthrax), or by ingestion of spores (gastrointestinal anthrax). CDC (2001) defines a confirmed case of anthrax as:

> A clinically compatible case of cutaneous, inhalational, or gastrointestinal illness that is laboratory confirmed by isolation of *B. anthracis* from an affected tissue or site, or other laboratory evidence of *B. anthracis* infection based on at least two supportive laboratory tests.

Inhalational anthrax begins with nonspecific symptoms—fever, cough, myalgia, and malaise. Onset of disease occurs 1 day to several weeks after inhalation of spores; the time of onset can depend on the dose. The initial nonspecific symptoms of inhalational anthrax typically are followed by the sudden onset of respiratory distress with dyspnea, cyanosis, and stridor in 2-3 days. Radiographical examination normally shows mediastinal widening that is indicative of hemorrhagic mediastinitis or pleural effusion. The anthrax toxins cause necrosis of the lymphatic tissue, leading to septicemia caused by the release of large numbers of *B. anthracis* into the circulatory system. Most cases of inhalational anthrax progress rapidly to death. The fatality rate may reach 95% even with antibiotic therapy, and autopsies typically reveal widespread hemorrhage and necrosis of multiple organs. The fatality rate in 2001 was 50% among the victims who contracted inhalational anthrax after exposure to weapons-grade anthrax spores.

Because inhalational anthrax is not transmissible, standard infection control

procedures are adequate and patient isolation is not required. Prophylaxis with the antibiotics doxycycline or ciprofloxacin before disease onset is effective—thousands of people were treated with those antibiotics after the 2001 attack. Vaccination also can protect against anthrax and has been used among U.S. military personnel. If untreated, *B. anthracis* spores can persist in the environment almost indefinitely. Environmental surface decontamination can be achieved using 0.5% hypochlorite (CDC, 1999) and that procedure typically is used in clinical and research laboratories.

The principal risk factor for inhalational anthrax previously was exposure to aerosolized spores related to textile mill processing of goat hair. Investigators could not determine why some workers became infected and others did not. Factors likely to increase infection rates included more intense exposure to *B. anthracis* spores through direct contact with unprocessed goat hair, weakened immune system, or concurrent disease (two patients with inhalational anthrax were suffering from chronic pulmonary disease). Other hypothesized risk factors included smoking and alcoholism. Although the investigations provided valuable information about diagnosis and the appropriate use of a vaccine to protect at-risk populations, they have not answered questions about the lowest infectious dose, the definition of a true exposure that warrants prophylaxis, and whether spores delivered in an envelope can create a residual risk after primary contamination. More research on anthrax in the natural setting is needed to define the risks from naturally occurring *B. anthracis* (Bales et al. 2002).

More than 95% of naturally occurring cases of anthrax are cutaneous. Inoculation of spores under the skin is necessary to establish infection. A small papule forms within hours to days, and then an ulcer, surrounded by vesicles, forms about a day later. Initial infection is not readily diagnosed because it resembles localized inflammation. Progression of cutaneous anthrax results in a painless eschar with edema. The fatality rate in untreated cases is 20%. However, the recovery rate from cutaneous anthrax is nearly 100% if it is treated with antibiotics such as penicillin or doxycycline.

Primary risk factors for cutaneous anthrax are direct physical contact with infected animals or commercial products contaminated with *B. anthracis* spores. Ranchers, farmers, butchers, and veterinarians are the professionals most at risk. The commercial products linked to human anthrax infection mostly are items made from imported goat skin or goat hair.

Humans contract gastrointestinal anthrax from ingesting undercooked contaminated meat. Gastrointestinal anthrax begins with nonspecific symptoms of nausea, vomiting, and fever, followed in most cases by severe abdominal pain. Mortality can reach 50%.

The number of anthrax cases reported in the United States decreased from an average of 35 per year in the 1950s to less than 1 per year since 1980. Most cases have been cutaneous anthrax. The last reported case of inhalational anthrax before October of 2001 was in 1976. A home craftsman acquired inhalational

anthrax from imported animal-origin yarn (Suffin et al., 1978). Bales and colleagues (2002) identified 49 anthrax-related field investigations conducted by CDC between 1950 and 2001. That work reports on 41 investigations to identify factors that could guide the public health response to an intentional release of *B. anthracis*. Agricultural settings (farms, contact with livestock, or both) accounted for 24 anthrax outbreaks; 11 were related to textile mills. Six outbreaks occurred in nonagricultural settings and involved such materials as anthrax-contaminated commercial products and contaminated cow bones. Thirty-eight of the 41 investigations were done in the United States; the rest were in Haiti, Paraguay, and Kazakhstan.

Although most of the 2001 anthrax exposures were recognized as they occurred and were traced to letters received in the mail, the first cases in Florida were not. The first indication of a problem was a patient arriving at the emergency room. An investigation subsequently pointed to the American Media International (AMI) building in Boca Raton, Florida. That case serves as an example of a delay between exposure and hazard identification that can be significant epidemiologically for defining and treating exposed populations. By the time patients display symptoms of inhalational anthrax, the disease can have progressed beyond treatment. Delays also influence decontamination: The period between agent release and identification can allow local spread of the agent. Secondary contamination also can occur as the agent is tracked on shoes, clothing, and other objects to locations remote from the original release site. When 63-year-old Robert Stevens died of inhalational anthrax in Florida October 5, 2001, a massive investigation began. An Associated Press report from October 7, 2001, stated that before the AMI building was identified as the source, "More than 50 health and law enforcement officials have fanned out across Palm Beach to track his movements over the past two months and look for other possible cases. Officials are going over medical records in four North Carolina counties that he might have visited recently." Only after extensive investigation was the AMI building identified as the source of Stevens' contact with the *B. anthracis* spores.

Plague

Plague is an infectious disease of animals and humans caused by the bacterium *Y. pestis*, a nonmotile, non-lactose-fermenting, gram-negative coccobacillus. *Y. pestis* has several virulence factors that cause host cell damage and protect the bacterial cells from phagocytosis and other host defense mechanisms.

Most cases of plague in humans occur as bubonic plague, which results when plague-infected fleas bite humans. Clinical bubonic plague is characterized by enlarged, tender lymph nodes; fever; chills; and prostration. Patients typically develop symptoms of bubonic plague 2-8 days after being bitten by an infected flea. There is a sudden onset of fever, chills, and weakness and the development of an acutely swollen tender lymph node (known as a bubo) up to 1 day later. The

bubo, which typically is 1-10 cm and extremely painful, often develops in the groin, axilla, or cervical regions.

Bubonic plague normally is not transmissible. However, in some cases, the bacteria spread systemically to cause septicemic plague, which is characterized by fever, chills, prostration, abdominal pain, shock, and bleeding into the skin and other organs. Septicemic plague can lead to a transmissible secondary pneumonia. It can result in sudden and intense clinical shock without signs of localized infection. Gangrene of acral regions, such as the digits and nose, also can occur in advanced septicemic plague. That process is believed to be responsible for the epithet "Black Death" that became associated with septicemic plague during the Middle Ages in Europe.

Direct inhalation of *Y. pestis* also can cause primary pneumonia (pneumonic plague). The pneumonic form is transmissible; it spreads as an aerosol from person to person. Pneumonic plague is characterized by fever, chills, cough, bloody sputum, retrosternal chest pain (from the enlarged lymph nodes in the mediastinum), and difficulty breathing. Those symptoms lead to rapid clinical shock and death if they are not treated early. If untreated, the mortality rate for pneumonic plague exceeds 50% (Ingelsby et al., 2000). However, if antibiotic and supportive therapies are administered within 24 hours of the onset of symptoms, the death rate can be reduced.

Aerosol spread of *Y. pestis* that could cause widespread pneumonic plague is considered a major bioterrorist threat (Inglesby et al., 2000). During World War II, Japan carried out biological weapons attacks using plague-infected fleas. In the case of a bioterrorist attack with *Y. pestis,* individuals would be likely to show signs of illness in 1-6 days. Symptoms include fever with cough and dyspnea and sometimes production of bloody, watery, or, less commonly, purulent sputum. Gastrointestinal symptoms, including nausea, vomiting, abdominal pain, and diarrhea, also can occur.

Inglesby and colleagues (2000) have described the epidemiology of plague. In nature, plague is an enzootic infection of rats, ground squirrels, prairie dogs, and other rodents. Historically, rats and their fleas have been the primary source of human infections—infected rat fleas were the sources of *Y. pestis* that caused major outbreaks of plague during the Middle Ages. Rat control has greatly limited the reservoir for *Y. pestis*, resulting in great diminution of plague. Rock squirrels and their fleas are the most frequent sources of human infection in the southwestern United States. For the Pacific states, the California ground squirrel and its fleas are the most common source. Many other rodent species—prairie dogs, wood rats, chipmunks, and other ground squirrels and their fleas—suffer plague outbreaks, and some species occasionally serve as sources of human infection. Deer mice and voles are thought to maintain the disease in animal populations but contribute less as sources of human infection. Other infrequent sources of infection include wild rabbits and wild carnivores that contract their infections from wild rodent outbreaks. Domestic cats (and sometimes dogs) could

readily contract plague from flea bites or from eating infected wild rodents. Cats can serve as a source of infection and sometimes are responsible for outbreaks of pneumonic plague.

Today there are typically 1000-2000 cases of plague annually worldwide (Perry and Fetherson, 1997). Most are cases of bubonic plague. During the 1980s, epidemic outbreaks of plague associated with domestic rats occurred annually in Africa, Asia, or South America. Almost all reported cases during the decade occurred in rural places among people living in small towns and villages or in agricultural areas, rather than in larger, more developed, towns and cities. Cases of pneumonic plague were found September 22, 1994, in the city of Surat, Gujarat, India. By September 26, 1994, several hundred pneumonic plague cases and numerous deaths had occurred (Ramalingaswami, 2001; Shah, 1997).

Of the 390 plague cases reported in the United States in the last half of the twentieth century, 84% were bubonic, with a fatality rate of 14%; 13% were septicemic, with a 22% fatality rate; and 2% were pneumonic, with a 57% fatality rate (CDC, 1997). During the 1980s, an average of 18 plague cases was reported in the United States each year. Most occurred in people under the age of 20, and the case-to-fatality rate was 14%.

The preferred treatment drug for plague infection has been streptomycin. If it is administered early, overall mortality can be reduced to a range of 5-14%. Gentamicin and other antibiotics, including doxycycline, also can be effective.

Given the available evidence, the Working Group on Civilian Biodefense (Inglesby et al., 2000) recommended that people who live or work in close contact with people who have confirmed or suspected pneumonic plague should receive antibiotic prophylaxis. Those who have less than 48 hours of antibiotic treatment should follow "respiratory droplet precautions"—wearing gowns, gloves, and eye protection—and wear a surgical mask. The working group also recommended avoidance of unnecessary close contact with patients with pneumonic plague until the patients have had at least 48 hours of antibiotic therapy and have shown clinical improvement. The use of standard respiratory droplet precautions also was recommended.

Given the available information, the working group (Inglesby et al., 2000) concluded that there was no evidence that residual plague bacilli pose an environmental threat to the population after the dissipation of the primary aerosol—although the group did not explicitly consider *Y. pestis* delivered in advanced weaponized formulations. Unlike *B. anthracis*, *Y. pestis* does not form endospores. *Y. pestis* also is sensitive to degradation by sunlight and heat and does not survive long outside the host. In laboratory settings, simple surface decontamination with bleach is sufficient and effective. According to the consensus position, there is no evidence to suggest environmental risk to humans in such settings, and thus environmental decontamination of an area exposed to an aerosol of plague is not necessary. In the World Health Organization (WHO) analysis (Inglesby et al., 2000), in the worst-case scenario, a plague aerosol was estimated

to be effective and infectious only for 1 hour. Although the data supporting those judgments is no longer available, it is suspected that the WHO committee that made the recommendations was not explicitly considering advanced weaponized formulations of *Y. pestis*.

Smallpox

Smallpox has been a great scourge of humankind. The disease was responsible for the deaths of about one-third of the European population during the Middle Ages. The smallpox virus particle is a complex structure about 300 nanometers (nm) in diameter, which is large enough to be viewed with a light microscope. The viral particle consists of DNA, protein, and lipids, with trace amounts of RNA. Several enzymes involved in RNA synthesis and modification are included. Smallpox belongs to the Poxviridae family, which is among the few DNA viruses that replicate in the cytoplasm of the infected cell. The virus most commonly enters the body via the airway. It is thought to infect the respiratory mucosa and spread locally to regional lymph nodes. After multiplying to high titer in the lymph nodes, the virus enters the bloodstream, causing a primary viremia. The viremia seeds many internal organs, such as the liver and spleen, where the virus undergoes multiple rounds of replication. When the titer is high enough, a secondary viremia ensues and the virus targets the skin and mucosa of the gastrointestinal tract. The ensuing rash is characteristic of the disease, progressing from macules to papules, vesicles, and finally to pustules that eventually scab. The rash begins on the head and trunk and progresses to the extremities. All of the lesions are at nearly the same stage in any one area of the body, and the lesions lead to the characteristic scarring. The time from infection to rash is about 2 weeks, which corresponds with the incubation period, during which the patient is asymptomatic. For 3-4 days, just before rash onset, there is dry cough, fever, and malaise, the so-called prodrome.

Smallpox belongs to the genus *Variola*. The mortality rate for variola major is about 40%. However, if the rash becomes hemorrhagic, mortality is close to 100%. Another form, variola minor or alastrim, has a low mortality rate of 3%. Humans are the only natural host; the absence of an animal reservoir allowed WHO to eliminate the disease through a worldwide program of vigorous, targeted immunization (Fenner et al., 1998).

Because smallpox is highly transmissible and the lyophilized form of the virus is stable at room temperature, smallpox was developed as a biological weapon in the former Soviet Union (Davis, 1999). Under the terms of a WHO agreement, smallpox preparations were to have been destroyed or placed in one of two repositories, the CDC in Atlanta, Georgia or in Russia. Whether there are additional stocks of smallpox beyond the official U.S. and Russian sites is not known. Before the invasion of Iraq in 2003, there was considerable concern that there might be smallpox stocks there (Davis, 1999). However, to date, there is no

evidence for the existence of smallpox in Iraq after 1992. Because smallpox was endemic in many areas of the world, old clinical specimens from patients might still exist and could serve as the source of a weapons-grade version of smallpox.

A live, attenuated virus, vaccinia—a close relative to smallpox—is an effective vaccine. The smallpox vaccine has not changed much since it was invented by Dr. Edward Jenner in the late eighteenth century. Although quite effective in protecting against smallpox, the vaccine can cause serious side effects, which can be deadly or cause severe sequellae. Immunosuppressed or immunodeficient people are at significant risk if exposed to the vaccinia virus vaccine. Reimmunization with the vaccinia virus every several years has been recommended for maximum protection. Because of the sequellae associated with immunization and the large number of people whose systems are immunodepressed, prophylactic immunization of the general population has not been seen as a viable public health strategy. Even an attempt to immunize frontline health care providers and first responders was not met with enthusiastic, widespread acceptance. Clearly, a safer vaccine is needed. Significant effort is being expended in this area and a more attenuated vaccinia virus, modified vaccinia ankara, is being tested. Development of an effective antiviral drug would be a highly desirable complement to vaccines. The drug most studied currently is cidofovir, which has been approved by the U.S. Food and Drug Administration for the treatment of cytomegalovirus. Cidofovir is nephrotoxic, so development of additional effective drugs is needed.

Although USAMRIID (2001) lists smallpox as stable, its persistence depends on environmental conditions and possibly on its formulation into weapons. In its natural form, variola major is sensitive to environmental conditions and has a short half-life outside of a human host. However, drying the virus renders it stable, and additional efforts to weaponize a dried form could be possible. Weaponized smallpox could be quite stable in indoor environments and so would present decontamination challenges similar to those posed by *B. anthracis*.

NATURAL BACKGROUND

Several potential agents of bioterrorism occur naturally worldwide. Although smallpox has been eradicated from all of its natural reservoirs, anthrax, plague, and tularemia are zoonoses endemic in many parts of North America. Botulinum spores are found in soil the world over: They have been recovered from agricultural products in marine sediments and from the intestines of animals and fish (Chin, 2000).

Plague is a zoonosis that occurs between rodents and fleas. Wild rodent plague is endemic in the western half of the United States. The bacterial infection can be transferred to other animals, including rabbits, and to other wild and domestic carnivores, which can transmit the infection to humans. Although the bacterium can remain viable for several weeks in water and moist grains, it is killed by several hours' exposure to sunlight (Chin, 2000). Background concen-

trations of plague in the environment are not likely to compromise decontamination efforts or to lead to false alarms.

Tularemia, another zoonosis, occurs throughout North America in a cycle of transmission between rabbits and ticks. Humans can become infected by drinking contaminated water; inhaling dust from contaminated soil, grain, or hay; or from contact with the pelts or paws of infected animals. Because tularemia cannot persist in the environment, its natural background is not likely to compromise decontamination efforts. As far as we know, although botulinum spores persist in the soil, they do not pose a public health threat.

Although the incidence of anthrax in humans and livestock has been decreasing in industrialized countries, it still occurs sporadically in bison and white-tailed deer in parts of Canada, and it is hyper-endemic in white-tailed deer in southwest Texas (Hugh-Jones, 1999). *B. anthracis* spores can remain viable in soil and dust for decades, especially around gravesites or near the carcasses of infected or diseased animals. Because of the resilient nature of anthrax spores in the environment and the possibility that they could confound decontamination assessment in areas where the disease is endemic in animals, determination of the environmental background is important.

Naturally occurring outbreaks of *B. anthracis* in animals have been sporadic in North America over the past few centuries. The first recorded case in the United States occurred in the 1780s. By the 1800s, anthrax was reported in the eastern United States and along the Mississippi River. The disease is believed to have spread across the country on the cattle trails. The incidence of the disease in animals gradually increased until the late 1950s, after which it declined rapidly because of the use of the Sterne veterinary vaccine.

The incidence of naturally occurring outbreaks of *B. anthracis* in animals has varied by time and place. A retrospective analysis of anthrax in the United States for 1900-2000 indicates that the occurrence in livestock at the county level was associated with chernozem soils, which are rich in calcium and have a neutral to alkaline pH. Those soils are found most often in prairies, grasslands, and areas of cereal grain cultivation. Counties with chernozem soil were found to be 4.7 times more likely to have outbreaks of the disease, and the death rate for livestock during outbreaks was 21 times higher than outbreaks occurring on nonchernozem soils. The study also assessed the incidence of outbreaks in close proximity to a cattle trail. Although death rates showed no difference, counties within 10 miles of a cattle trail were 2.3 times more likely to have outbreaks of *B. anthracis* (K. Smith, presentation to the committee, March 29, 2004).

Officials at CDC have noted the importance of determining natural background for *B. anthracis* in establishing realistic thresholds for cleanup efforts, particularly in areas where outbreaks in animals have occurred in the past (Roos, 2004). Although a study of *B. anthracis* spore contamination between outbreaks in endemic regions of northern Canada (Dragon et al., 2001) reported high environmental concentrations of spores, they appeared limited to scavenger feces and

to sites where diseased carcasses had been found. Although epidemiological investigations were done for "occupational" outbreaks in textile mills and among veterinarians, and in agricultural settings with human and animal cases, there have been few systematic studies of the natural background of *B. anthracis* spores in the environment.

Investigations of epizootics—outbreaks of disease affecting many animals of kind at the same time—detailed in a CDC (1961) report included soil sampling programs in Mississippi, Louisiana, Wyoming, Louisiana, and Arkansas. Positive samples were associated with moist soil and an alkaline pH. Pepper and Gentry (2002) reviewed the literature on the ecology and persistence of *B. anthracis* and other *Bacillus* species in soil. The authors pointed out the need for additional research on the conditions that favor *B. anthracis* survival in soil, the determination of whether it undergoes a growth cycle, and whether *B. anthracis* virulence genes could be transferred to other soil microorganisms.

The Center for Environmental Biotechnology at Lawrence Berkeley National Laboratory in California is creating the first database of naturally occurring airborne bacteria from samples collected throughout the United States. The study, funded by the Department of Homeland Security, will identify background strains and concentrations of bacteria contained in aerosols from major metropolitan centers. The database will provide information by season and geographic region and thus facilitate a better understanding of background bacteria in the air we breathe (Krotz, 2004). The information also will be useful for comparison with data from environmental sensors, for example, to help scientists determine whether a detected pathogen might have come from a natural source or is a result of an intentional release.

Although the foregoing information suggests that over time humans and animals have been exposed to naturally occurring *B. anthracis* and have either avoided infection or become infected and survived to develop immunity, the committee cautions that such cases are not useful for establishing "acceptable" residual contamination in public buildings, for several reasons.

Preparation of biological agents for use as weapons could vary and alter the infectivity of the agents with respect to the natural form. Given the variability in infectivity and virulence in biological agents that is attributable to natural variation or to processing as weapons, we should not presume that the results of the epidemiological studies described here can be extrapolated to human exposure to *B. anthracis* spores during an act of bioterrorism.

Although crudely prepared *B. anthracis* spores might have characteristics that closely resemble the natural form, they are not likely to be found as natural background in indoor facilities. Therefore, the concept of natural background is not applicable to the case of *B. anthracis* in indoor facilities.

In areas where there is a natural background of *B. anthracis*, such as woolen mills, the people occupying the space might have developed immunity to the

agent as a result of constant exposure. Occupants of public facilities where there is no detectable background are unlikely to do so and might be more susceptible to the agent regardless of preparation.

CONCLUSION

Although individuals in some areas encounter harmful agents that occur naturally in the environment and show few or no health effects, for two reasons we caution against extrapolation for determining an acceptable amount of residual contamination by harmful agents released during a bioterrorist attack. First, it is unlikely that a detectable natural background of the harmful agent would be present in indoor public facilities. Indoor air-monitoring equipment installed in many facilities has not detected those agents. In the past century, there have been few known cases of anthrax, smallpox, plague, or Ebola in which the disease was acquired through exposure to a natural background concentration of the agent. The exceptions have been in workers who acquired anthrax at woolen mills and in people who acquired smallpox, plague, or Ebola in hospitals where infected patients were being treated. Second, microorganisms of the same species can vary in infectivity and virulence as a result of variations among strains or because of the weaponization processes that alter their characteristics. The fact that people can tolerate a background concentration of naturally occurring pathogens does not guarantee that they will tolerate a similar concentration in weaponized form. Thus, even though scientists have extensive experience with disinfection of contaminated facilities, such as microbiology laboratories or hospital wards, there is limited knowledge about decontamination of facilities that have been intentionally contaminated with biological agents.

FINDINGS AND RECOMMENDATIONS

Finding 2-1

Naturally occurring infectious-disease hazards provide much information that is useful for biodefense consequence management planning, but weaponized biological agents could pose special threats that are distinct from those attributable to naturally occurring hazards, especially when it comes to decontamination.

Recommendation 2-1

Decontamination decisions and plans should consider the natural characteristics of a specific pathogen and the weaponization characteristics of that agent. Weaponized agents can vary in infectivity and virulence as a result of formulation, and the presence of a natural background of weaponized agents (such as weaponized *B. anthracis*) is unlikely in indoor public facilities. Given the uncertainties in the characteristics of the weaponized agents, it is impossible to estab-

lish acceptable thresholds below which exposure to such weaponized agents would pose zero risk.

REFERENCES

Alibek, K. 1999. Biohazard: The Chilling True Story of the Largest Covert Biological Weapons Program in the World—Told from Inside by the Man Who Ran It. New York: Dell Publishing.

Atlas, R.M. 2001. Bioterrorism before and after September 11. Critical Reviews in Microbiology 27:355-379.

Atlas, R. 2002. Bioterrorism: from threat to reality. Annual Reviews in Microbiology 56: 167-185.

Bales, M.E., L. Dannenberg, P.S. Brachman, A.F. Kaufmann, P.C. Klatsky, and D.A. Ashford. 2002. Epidemiologic response to anthrax outbreaks: field investigations, 1950-2001. Emerging Infectious Diseases 8(10): 1163-1174.

Carus, W.S. 2001. Bioterrorism and Biocrimes: The Illicit Use of Biological Agents Since 1990. Working Paper, Center for Counterproliferation Research. Washington, DC: National Defense University.

CDC (U.S. Communicable Disease Center). 1961. Final Report from Department of Health, Education and Welfare, United States Public Health Service, Bureau of State Services, Communicable Disease Center to Department of Defense, Department of the Army, Chemical Corps, Fort Detrick, Frederick, Maryland. Contract Number FD6-404-6302.

CDC (U.S. Centers for Disease Control and Prevention). 1997. Fatal human plague—Arizona and Colorado, 1996. Morbidity and Mortality Weekly Report 46(27): 380-382.

CDC. 1999. Bioterrorism alleging use of anthrax and interim guidelines for management—United States, 1998. Morbidity and Mortality Weekly Report 48: 69-74.

CDC. 2001. Update: investigation of anthrax associated with intentional exposure and interim public health guidelines. Morbidity and Mortality Weekly Report 50(41): 889-893.

CDC. 2004a. Frequently Asked Questions About Smallpox. [Online]. Available at: http://www.bt.cdc.gov/agent/smallpox/disease/faq.asp (accessed on November 16, 2004).

CDC. 2004b. Frequently Asked Questions About Plague. [Online] Available at: http://www.bt.cdc.gov/agent/plague/faq.asp (accessed on November 16, 2004).

Chin, J., ed. 2000. Control of Communicable Diseases Manual, 17th edition. Washington, DC: American Public Health Association.

Cole, L.A. 2003. The Anthrax Letters. Washington, D.C.: Joseph Henry Press.

Davis, C.J. 1999. Nuclear blindness: an overview of the biological weapons programmes of the former Soviet Union/Russia and Iraq. Emerging Infectious Diseases 5(4): 509-512.

Dragon, D.C., R.P. Rennie, and B.T. Elkin. 2001. Detection of anthrax spores in endemic regions of northern Canada. Journal of Applied Microbiology 91: 435-441.

Fenner, F., D.A. Henderson, I. Arita, Z. Jezek, and I.D. Ladnyi. 1998. Smallpox and Its Eradication. Geneva: World Health Organization.

Hugh-Jones, M. 1999. 1996-97 global anthrax report. Journal of Applied Microbiology 87(2): 189-191.

Inglesby, T.V., D.T. Dennis, D.A. Henderson, J.G. Bartlett, M.S. Ascher, E. Eitzen, A.D. Fine, A.M. Friedlander, J. Hauer, J.F. Koerner, M. Layton, J. McDade, M.T. Osterholm, T. O'Toole, G. Parker, T.M. Perl, P.K. Russell, M. Schoch-Spana, and K. Tonat. 2000. Plague as a biological weapon. Medical and public health management. Journal of American Medical Association 283: 2281-2290.

Kolavic, S.A., A. Kimura, S.L. Simons, L. Slutsker, S. Barth, and C.E. Haley. 1997. An outbreak of *Shigella dysenteriae* type 2 among laboratory workers due to intentional food contamination. Journal of American Medical Association 278(5): 396-398.

Krotz, D. 2004. Cataloging airborne bacteria, city by city. Lawrence Berkeley National Lab Science Beat: March 24, 2004. [Online] Available at: http://www.lbl.gov/Science-Articles/Archive/sb-ESD-cataloging-bacteria.html.

Meselson, M., J. Guillemin, M. Hugh-Jones, A. Langmuir, I. Popova, A. Shelokov, and O. Yampolskaya. 1994. The Sverdlovsk anthrax outbreak of 1979. Science 266: 1202-1208.

NRC (National Research Council). 2004. Biotechnology Research in an Age of Terrorism. Washington, DC: The National Academies Press

Pepper, I.L. and T.J. Gentry. 2002. Incidence of *Bacillus anthracis* in soil. Soil Science 167: 627-635.

Perry, R.D., and J.D. Fetherson. 1997. *Yersinia pestis*—etiologic agent of plague. Clinical Microbiology Reviews 10: 35-66.

Ramalingaswami, V. 2001. Psychosocial effects of the 1994 plague outbreak in Surat, India. Military Medicine 166: 29-30.

Roos, R. 2004. CDC seeks to determine natural background level of anthrax. University of Minnesota Center for Infectious Disease Research & Policy (CIDRAP) News: Nov 16, 2004. [Online] Available at: http://www.cidrap.umn.edu/index.html.

Shah, G. 1997. Public Health and Urban Development: The Plague in Surat. Thousand Oaks, California: Sage Publications.

Smithson, A.E., and L.A. Levy. 2000. Ataxia:* The chemical and biological terrorism threat and U.S. response. Washington, DC: Henry L. Stimson Center.

Suffin, S.C., W.H. Carnes, and A.F. Kaufmann. 1978. Inhalation anthrax in a home craftsman. Human Pathology 9: 594-597.

Torok, T.J., R.V. Tauxe, R.P. Wise, J.R. Livengood, R. Sokolow, S. Mauvais, K.A. Birkness, M.R. Skeels, J.M. Horan, and L.R. Foster. 1997. A large community outbreak of salmonellosis caused by intentional contamination of restaurant salad bars. Journal of the American Medical Association. 278(5): 389-395.

USAMRIID (U.S. Army Medical Research Institute of Infectious Diseases). 2001. Medical Management of Biological Casualties Handbook, Fourth Edition. Fort Detrick, Frederick, Maryland: USAMRIID.

Wheelis, M. 1999a. Biological Warfare Before 1914. Pp. 8-34 in Biological and Toxin Weapons: Research, Development and Use from the Middle Ages to 1945, E. Geissler and J.E.v.C. Moon, Eds. Oxford: Oxford University Press.

Wheelis, M. 1999b. Biological Sabotage in World War I. Pp. 35-62 in Biological and Toxin Weapons: Research, Development and Use from the Middle Ages to 1945, E. Geissler and J.E.v.C. Moon, Eds. Oxford: Oxford University Press.

Wheelis, M. 2003. A Short History of Biological Warfare and Weapons. In M.I. Chevrier, K. Chomiczewski, M.R. Dando, H. Garrigue, G. Granaztoi, and G.S. Pearson, eds. The Implementation of Legally Binding Measures to Strengthen the Biological and Toxin Weapons Convention. ISO Press Amsterdam.

3

Policy Precedents in Decontamination

The subject matter of this report, determining when a facility is safe for use, is not a new policy-making dilemma. The prospect of remediating a biologically contaminated public facility, however, requires that policy makers consider both the biological nature of the hazard and the public nature of the building. The public nature of the building adds a social dimension to policy and decision making because the public's perception of the event and its aftermath must be taken into account. Another dimension is national security. The range of policy precedents in decontamination reviewed here provides lessons relevant to each dimension:

- Routine microbial decontamination of water and food supplies
- Biosafety practices in laboratories and environmental infection control in hospitals
- Decontamination procedures and safety programs for biological weapons research and testing facilities
- Cleanup of hazardous-waste sites
- Remediation of radioactive waste within the nuclear weapons complex

Although not related to biological hazards, the remediation of waste sites under the Superfund program and of radioactive waste within the nuclear weapons complex are instructive in the special considerations that arise in the context of affected individuals who face involuntary exposures to unfamiliar hazards. The legacy of secrecy within the nuclear weapons complex (Fehner and Gosling, 1996; O'Leary, 1997)—as it relates to public confidence in government declara-

tions regarding safety—is instructive in the need for transparency in public health matters that arise against a national security backdrop.

MICROBIAL DECONTAMINATION IN FOOD AND WATER SUPPLIES

Foodborne and waterborne infections are commonplace examples of the need to reduce pathogen occurrence in environments that have a direct effect on human health. Microbial risk assessment, addressed in greater detail in Chapter 4, is a useful tool for setting standards in food and water safety, making it appropriate for use in the current application.

The first direct use of microbial-risk-based criteria for regulating exposure to pathogens in the United States was in the U.S. Environmental Protection Agency (EPA) water quality criteria for recreational waters (EPA, 1986a). That document listed water quality limits that were set so that a risk (from recreational contact such as swimming) of 0.008 illnesses/bather-day (for fresh water) to 0.019 illnesses/bather-day (for marine water) per exposure resulted; experts deemed that an acceptable risk to the public (EPA, 1986a).

Shortly thereafter, the Surface Water Treatment Rule mandated that all water purveyors that used surface water introduce treatment sufficient to provide adequate control of pathogens. In the rule's development, treatment was to achieve a residual risk of infection of less than 1/10,000 per year based on microbial risk assessment, even if there was a high concentration of pathogens in raw water (Macler and Regli, 1993).

In food safety, canning, the first large-scale method of industrial food preservation, relies on heat to minimize risk from pathogens and to reduce spoilage. A criterion that is sufficient to provide 12 logs of inactivation (that is, only one out of 1×10^{12} spores would remain active) of *Clostridium botulinum* spore—referred to as a "botulinum cook"—is commonly applied even though the criterion does not necessarily result in a sterile product (Farkas, 1997). More recent concerns on food safety—particularly for less thoroughly processed foods—have led to increasing attention to providing a scientific basis for food safety criteria.

A committee of the Institute of Medicine (IOM, 2003) has examined food safety. Among its conclusions are two that are germane to the current report:

> There is a need to define "acceptable levels" of hazard reduction at critical points linked to public health objectives. The Food Safety Objective concept can help establish this link and define these levels, and it can also provide a theoretical framework to relate performance standards to public health objectives.
>
> Quantitative microbial risk assessment offers the scientific tools to define the most effective solutions for lowering consumer exposure to foodborne microbial hazards.

A food safety objective is a quality measure to control risk at a particular surveillance point in the food-processing chain. Specifically, it is "the maximum frequency and/or concentration of a (microbiological) hazard in a food at the time of consumption that provides the appropriate level of protection" (International Commission on Microbiological Specifications for Foods, 2002). The objective can be derived from a dose–response relationship to the pathogen in question (Havelaar et al., 2004). However, a risk management decision on *acceptable* risk must still be made.

BIOSAFETY IN MICROBIOLOGICAL AND BIOMEDICAL LABORATORIES

Humans and microorganisms cohabit the world, and their interactions lead to disease occasionally. Society takes steps to reduce the chances of disease among individuals and population (for example, by sterilizing food and water supplies to kill harmful microorganisms). Some people, however, do have extensive intentional contact with infectious agents during work or study in microbiology and biomedical laboratories. Biological safety policies and procedures have evolved to ensure that laboratory researchers and technicians are protected against infectious disease and prevented from unintentionally releasing pathogens into the environment or the community. Two facts are relevant. First, safety is a top priority for people who routinely face the possibility of exposure to pathogens. Second, laboratory decontamination protocols are essential parts of a comprehensive biological safety program.

Safety procedures used in performing necessary tasks, along with laboratories' physical containment features, provide the framework in which people can work in biologically contaminated environments. The development and implementation of laboratory safety guidelines form the foundation for biological safety in any laboratory that uses microbiological organisms that can cause infectious diseases (DHHS, 1999). Basic elements of biosafety include the following:

- Staff have an in-depth understanding of the microorganisms with which they work.
- Staff are well versed in safety and procedures, including the correct use of personal protective equipment.
- Continuing education is provided in new technologies, including new equipment or procedures that promote laboratory safety.
- Architecture and equipment designs are chosen for the physical containment of pathogens.
- Procedures are established for the decontamination of work surfaces.

Microbiological and biomedical laboratory operations demonstrate that under carefully controlled situations, humans can come into extensive contact with

pathogens without harm. Protective features, however, are eminent in a laboratory's physical structure, equipment, personal protective gear, personnel training, and accepted professional practice. There also are prescribed procedures in the event of a spill or other accident. One cannot generalize from this special environment to public buildings whose occupants would not necessarily have extensive knowledge of microbiology or biosafety procedures, and who have not consented as such, to exposure to dangerous microorganisms.

ENVIRONMENTAL INFECTION CONTROL IN HEALTH CARE FACILITIES

Hospitals and other health care facilities implement administrative and engineering procedures to eliminate or control infectious agents that cause disease (Sehulster and Chinn, 2003). Health care settings are characterized both by a higher likelihood of the introduction or presence of infectious agents and by their institutional duty to protect patients, particularly those whose immune systems are compromised and vulnerable to infection. The health of workers and patients can be at stake whether the threat is an environmental pathogen such as *Legionella* spp. or an airborne pathogen like *Mycobacterium tuberculosis.* Health care facilities have developed infection control and epidemiological functions to protect a broad range of building occupants—from health care professionals, to nonmedically trained workers, to patients and visitors.

Most relevant to this report is the fact that health care facilities, to a greater or lesser degree, retain a cadre of professionals, many of whom work on site, who are trained specifically to address issues of microbial contamination and infectious disease. Those facilities often employ infection control practitioners, infectious-disease experts, epidemiologists, employee health and safety personnel, and facility engineers. There are also third-party oversight mechanisms, such as the Joint Commission on Accreditation of Healthcare Organizations, that evaluate the infection control performance of health care facilities. In contrast, public buildings, such as airports, are not routinely staffed by people who would be familiar with infectious agents and disease transmission. Nor are the owners or operators of public facilities necessarily familiar with microbiological, epidemiological, or larger public health principles.

DECONTAMINATION OF U.S. ARMY BIOLOGICAL WARFARE LABORATORIES

The U.S. Army Biological Laboratories at Fort Detrick, Maryland, were in operation from March 1943 until July 1972. Their mission was to conduct offensive and defensive research with highly pathogenic agents and/or their toxins, with the ultimate goal of protecting the United States. At the start of the program, safety procedures, vaccines, antibiotics, medical treatment regimens, and con-

tainment facilities were limited, and there were many unknown operational elements and unrecognized risks to military and civilian employees. Because of the high-risk nature of the research and the sizeable population facing possible exposure (1500-1700 personnel), a comprehensive safety program was put in place and continuously improved. That program—which included decontamination policies and protocols—was successful in terms of technical rigor, health and safety outcomes, and employee confidence, according to records available to this committee.

Several factors contributed to the effectiveness and credibility of the program, beginning with the fundamental priority given to health and safety: Any research activity that would compromise employee safety, cause damage to facilities, allow release of agents into the environment, or permit cross-contamination among research materials or laboratory animals could not be initiated—any of those incidents halted the research. Employee safety was not compromised for program expedience or financial savings.

A dedicated, well-educated, large scientific safety staff (up to 30 people) was appointed at the start of the program. The staff included well-trained laboratory technicians and Ph.D. scientists. A physician served as the safety director. Safety responsibilities enveloped examination of every task and the conduct of research studies to evaluate hazards associated with laboratory operations, production, equipment, and facilities design. Procedures and decisions were transparent to those who might have been affected. Also, safety staff members were available to all employees, outside the chains-of-command structure, to address concerns. That open-door policy provided a forum in which to evaluate employee concerns, identify deficiencies regardless of magnitude, answer inquiries, render assistance, and provide daily safety awareness.

Senior management instituted the operating principle that no punitive reprisal, punishment, or fault finding was to occur in an aftermath of an accident, error in judgments, or equipment or facility damage, thus allowing the laboratories to learn from every experience to prevent reoccurrence. The policy was approved by the Military and Civil Service Commission as an exception for Fort Detrick, and it mandated reporting of incidents to the safety staff for evaluation.

A biological safety research program assessed all operational aspects, equipment, and facilities development, and it provided investigative mechanisms for each laboratory or production procedure. The program eventually evolved into the scientific discipline now known as biological safety or biosafety. It identified procedures to ensure safety in every component of work with pathogenic agents, including tasks that involved toxins, genetic manipulation, and production of agents and vaccines. An extensive laboratory safety training program was maintained for the lifetime of the program.

Before agent research could be initiated, a screening evaluation was conducted. The evaluation involved library research to glean knowledge and assess risk; identify a disinfectant of choice if possible; assess biological decay param-

eters, sterilization conditions, heat stability, vaccine availability, antibiotic sensitivity, or resistance; and delineate a medical treatment regimen. The evaluation usually was performed by a principal investigator, and often it involved members of the safety staff before an agent could be used or placed in the program.

Apart from administrative and engineering controls to protect against exposure, from inception, the Biological Warfare Laboratories established a comprehensive medical surveillance and treatment program that encompassed prophylactic vaccination; complete medical surveillance for any illness, either suspect or frank; and complete treatment for known or suspected illness. Before any employee could seek medical assistance from a private physician, he or she had to obtain clearance from post physicians. Employees had amounted to free medical care because of the responsibility of the facility physician to rule out all possibility of laboratory-acquired illness. The facility maintained a full medical staff, an outpatient clinic, and a complete isolation-quarantine hospital.

The Fort Detrick case is instructive on several matters. The health and safety of occupants were core objectives in that environment, where weaponized pathogens were produced and studied. A comprehensive set of safeguards was in place both to prevent exposure in the first place and to monitor for any untoward effects should exposure occur by accident. Medical care for occupationally acquired infection was a given. Employees trusted the decisions and interventions of a dedicated and trained safety staff, against the backdrop of a larger policy that no research activity should proceed that might endanger staff.

There are limits to generalizing from this case to the matter at hand. Those facilities were used exclusively for biodefense purposes by a typically healthy, robust, vaccinated population and employees were under the control of a central authority, the U.S. Army. One implication of that important fact is that it is probable that there was more cultural homogeneity at Fort Detrick than would be the case in a major American airport. People at Fort Detrick generally would be expected to share assumptions about what counted as relevant expertise and who had the ultimate authority to make decisions regarding acceptable risk. In the case of an American airport, there would be more diversity among people involved, thus there would be more points of view and more potential for social conflict.

DEVELOPMENT OF SUPERFUND AND REMEDIATION PLANS

The policy question "How clean is clean enough?" arose early in the development of the Superfund program. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, 43 USC 103) was enacted in 1980 in response to growing public and government concern over several highly visible and dangerous contaminated sites, most notably in the community of Love Canal, New York. CERCLA provided a mechanism for site identification and, ultimately, financing for response and remediation through mechanisms for assignment of liability and the establishment of trust funds. At some Superfund sites, it

was necessary to decontaminate the interior of buildings. Those cases are directly analogous to the problem addressed in this report, and the remedy chosen is (at least in part) decontamination of the building and interior components to permit at least partial reoccupancy. One example was the cleanup of the Grand Street Mercury site in Hoboken, New Jersey (NJ0001327733). In that case, mercury contamination of a residential structure was caused by that building's prior use as a factory for manufacture of mercury vapor lamps. Cleanup criteria (including allowable concentrations of mercury in ambient air) were set for the remediation so that rehabitation could be permitted. CERCLA also provided guidance on the extent to which remediation was to be conducted. A study by the General Accounting Office (GAO) noted, however, that the original National Contingency Plan consistently left cleanup targets vague (GAO, 1985). The plan required only that the selected action "be cost-effective and mitigate and minimize damage to provide adequate protection of public health and welfare and the environment."

Great heterogeneity thus emerged among the design goals of the initial remediation projects, fueling local and national controversy over the quality of cleanup operations. How could the public and other interested parties be sure that remediation was effective when there was no consensus about the endpoint? GAO identified four principal options for resolving the controversy (GAO, 1985):

- Restore sites to their "original" condition by completely removing all contaminants.
- Set uniform national standards on a contaminant-by-contaminant basis.
- Require application of "best available technology" to the cleanup.
- Deal with immediate and significant problems, but defer further action until more detailed criteria were developed.

The 1986 reauthorization (Superfund Amendments and Reauthorization Act [SARA]) was designed, in part, to help address the gap in safety and performance standards (EPA, 1986b). The key points of SARA (EPA, 1986b) that are relevant to this report are as follows:

- SARA gives weight to the use of permanent remedies and innovative treatment technologies.
- It requires Superfund actions to account for other state and federal standards and regulations in setting cleanup goals.
- It increases state and local involvement in investigation and site selection.

The passage of SARA caused EPA to review other environmental programs and develop cleanup guidelines concordant with goals for public health established in other programs (Applicable or Relevant and Appropriate Requirements), to weigh the qualitative attributes of the potential remedies in the decision-making process (permanence and innovation), and to involve stakeholders in

BOX 3-1
Evaluation of Superfund Site Cleanup: More Art than Science

"Risk assessment and site cleanup will usually have to proceed on the basis of very limited knowledge for determining the precise level of cleanup necessary. There is simply not enough technical and health-related information available to know precisely what the level of cleanup at any specific site should ultimately be. The selection of appropriate cleanup technologies and the ultimate evaluation of cleanup performance remain somewhat of an art rather than a science. Restoring sites to pristine or background levels or requiring the use of best available technology is probably not practical or economical based on a rational cost, benefit analysis."

"An ideal remedial cleanup should provide complete and total protection of human health and the environment from the remediated site contamination. However, complete protection is neither technically feasible nor affordable. There will always be some level of risk remaining at a remediated site."

(Wentz, 1989).

decision making. However, even after SARA, the dominance of qualitative and subjective aspects of decision making remained (Box 3-1).

The practice of applying technically based standards within the selection of remedies, for the most part, remains unchanged since SARA, and EPA does not generally clean up to below natural background concentrations. However, where the anthropogenic background concentrations exceed acceptable risk-based concentrations—and where EPA has determined that a response action is appropriate—the agency's goal is to develop a comprehensive response to area wide contamination (EPA, 1997). There has been increasing emphasis in recent years on stakeholder involvement in determining the fate of Superfund sites. Inclusion of interested and affected parties is meant to address two aspects of hazardous-waste-site management. The first acknowledges that cleanup is, ultimately, a values-driven endeavor. EPA has recognized and the National Research Council's recommendations have affirmed (NRC, 1983, 1996) that when public policy incorporates public health and environmental aims, decision making necessarily involves factors beyond the technical aspects of risk assessment, that is, a technically validated definition of potential danger (Figure 3-1).

Many discussions on the possibility of restoring a given site to its "original" condition by complete removal of all contaminants have included assessments of technical feasibility and cost effectiveness. There is not necessarily agreement, from a public policy standpoint, about what constitutes *acceptable* cleanup. In-

FIGURE 3-1 EPA risk management decision framework. Source: EPA, 2000.

volving the full range of interested and affected parties is seen as vital to reaching consensus. A second dimension for inclusive decision making is the realization that the people and groups that face the most immediate or direct health consequences from exposure to a hazardous waste site have the highest stakes in the cleanup of a Superfund site. Their confidence in whether or not remediation decisions adequately protect their health could not be ensured unless they participated in deliberations about what constituted reasonable action by responsible parties in the absence of perfect solutions (NRC, 1996).

REMEDIATION EXPERIENCES IN THE U.S. NUCLEAR WEAPONS COMPLEX

The U.S. Department of Energy (DOE) manages more than 100 sites contaminated with radiological and chemical by-products that have been amassed during a half-century of nuclear weapons production (Burger et al., 2003). The largest of those sites (such as Oak Ridge, Tennessee; Savannah River, South Carolina; Hanford, Washington) have hundreds of individual waste sites within their boundaries that require remediation. Cleanup challenges facing DOE include the sheer magnitude of remediation projects—DOE cleanup constitutes 20% of the world's environmental remediation market. But there also are the compounded hazards and technological difficulties posed by long-lived radioac-

tive contaminants that are mixed with toxic chemicals and, most important for this study, the lack of public and regulator trust in DOE and its site operators.

From its inception, the management of the nuclear weapons complex was characterized by secrecy and self-regulation (Fehner and Gosling, 1996). The wartime Manhattan Engineer District, under the U.S. Army Corps of Engineers, carried out projects without any appraisal by local populations or public regulators. Reorganized after the World War II into the civilian-controlled Atomic Energy Commission (AEC), the weapons complex continued to be exempt from external licensing and regulation. AEC—a predecessor to DOE—held the authority to establish its own standards, oversee contractor health and safety, and manage the distribution of nuclear materials. The commission's work was cast in terms of national security, and AEC managers and operators saw the manufacture and development of nuclear materials as their primary mission; waste and environmental concerns were of less immediate consequence or importance.

DOE's claim to self-regulation was challenged in the 1980s after public disclosures about toxic releases, in reaction to the work of environmental activist groups, and as a result of landmark legal decisions that opened the agency up to EPA and state regulation. The question of who exactly should perform risk assessments for hazardous-waste sites within the weapons complex generated significant controversy (Henry et al., 1997; NRC, 1994). The public generally has been unwilling to accept DOE's official assurances about the health effects of exposure to nuclear-related activities because of a core conflict of interest for the agency and its predecessors. The government is responsible for the production and testing of nuclear weapons, and it has been the nearly exclusive source of funding for U.S. radiation research in general and for radioactive fallout monitoring, dose reconstructions, and epidemiological investigations, in particular (Hoffman et al., 2002).

Revelations about deliberate deception about environmental and worker exposures also greatly undermined public confidence in DOE pronouncements about health matters (Ledwidge et al., 2004; Thomas, 2001). Scientists who failed to acknowledge publicly the limits of their knowledge regarding radiation health effects also engendered mistrust. Public skepticism about DOE as a source of information on radiation exposure and health risks has, in some cases, necessitated independent reevaluations of cleanup standards (Till and Meyer, 2001). Requests for reevaluations, although reasonable, incur additional costs as do the resulting delays in cleanup operations.

In reviewing the major lessons from the U.S. experience on long-term management of areas contaminated with radioactive materials, one top DOE official characterized the "absolute key to success" as "the establishment of open, honest and inclusive communications and decision-making" with affected populations (Jones, 2004). The corollaries to this are the need to create opportunities to reach mutual agreement on expectations for cleanup endpoints and measures of success before taking action, and to provide the necessary financial and technical support

so that the involved parties are confident that technical assessments are uncompromised; that is, that the assessments are based on science and free from conflicts of interests (Burger, 2002; Jones, 2004). Stakeholder involvement provides valuable returns in the form of local knowledge that can lead to better assessments of risk, greater public confidence in the science-based tools that support decision making, and the cultivation of participants who can champion the result within the larger affected community (Till and Meyer, 2001).

Review of policy precedents for a range of decontamination experiences—radiological, chemical, and biological—presents guiding principles that are applicable to the remediation of biologically contaminated public facilities. It is important that parties whose personal health and property are affected have adequate representation in decision making about decontamination and reopening of a facility. Restoration decisions that solicit neither consent nor input from affected parties are likely to be questioned or dismissed altogether. The history of radioactive-waste remediation within the nuclear weapons complex underscores the importance of open and inclusive decision making: Government secrecy, evoked in the name of national security, greatly diminished public confidence in official declarations about environmental health and safety. Finally, biological safety policies and practices to protect people in hospitals and laboratories—places that present a greater chance of exposure to pathogens—incorporate decontamination and sterilization as part of comprehensive safety systems that include medical surveillance to identify inadvertent exposures and resulting illnesses. Postevent medical monitoring is a wise practice in the context of a biologically contaminated public building.

FINDINGS AND RECOMMENDATIONS

Finding 3-1

Determining acceptable risk is a complex issue: Willingness to accept risk varies from person to person, from situation to situation, and from culture to culture. Managing risk also is complex: Different people have different ideas about how much responsibility the government or the owners and operators of public facilities and lands have to limit public exposure to risk. Those issues have been considered in many situations, and many policy-making lessons can be learned from events involving Superfund and the U.S. Department of Energy.

Recommendation 3-1

In contemplating how to respond to potential biological attacks, authorities should base their plans on lessons from the experiences of others who have dealt with decontamination issues in the broadest sense; they should not consider their charge a completely novel task. Decision making about a facility contaminated as the result of a biological attack should be mindful of the critical policy dimen-

sions of the biological quality of the hazard, the public nature of the building, the public's perception of an attack, and the event's national security implications.

Finding 3-2
If safety-related standards and protocols are devised and implemented behind closed doors, without the consent or input of affected and interested parties, those standards are likely to be questioned or rejected outright. Lack of transparency for policy decisions that directly affect public health—even in the context of a proclaimed national security interest—can severely erode public confidence. The establishment of a formal planning procedure that involves relevant stakeholders before an event should expedite the response and confer legitimacy for decisions made during and after decontamination.

Recommendation 3-2
Representatives of affected parties should be involved in risk management decision making, and they should participate in the technical discussions needed to make decisions. Engaging the people whose well-being is most at stake helps ensure their greater confidence in the outcome of risk-based decisions. Those who provide the technical information should be independent experts who are free of conflicts of interest, so that they can give the highest priority to protecting public health. Stakeholder involvement in risk assessment and management provides valuable returns: local knowledge that can contribute to a more robust definition of the danger, greater public confidence in scientific tools that support public policy, and more widespread acceptance of the legitimacy of the results.

Finding 3-3
People and microorganisms cohabit the world; their interactions sometimes result in human disease. Nonetheless, in settings where people risk exposure to pathogens (laboratories, hospitals), biological safety policies can protect against human disease. Decontamination is not a standalone activity, but part of a larger set of controls over dangerous microorganisms and their potential health effects. The domestic institution that routinely dealt with weaponized pathogens—the U.S. Army Biological Warfare Laboratories—developed a comprehensive set of biological safety programs to control those pathogens. Protective measures ranged from preemptive vaccination to medical monitoring and treatment for inadvertent exposures.

Recommendation 3-3
Integrated protection for human health is the most prudent policy in the context of a facility contaminated as the result of a biological attack. After a facility has been decontaminated, some type of medical monitoring is critical to ensure confidence that a facility is safe, and the purpose and outcome of medical monitoring

should be made transparent to affected parties. In the event of any incident in the future, a centralized and sustained effort should be organized to track the health of those exposed, or potentially exposed, to pathogens.

REFERENCES

Burger, J. 2002. Restoration, stewardship, environmental health, and policy: understanding stakeholders' perceptions. Environmental Management 30(5): 631-640.

Burger, J., T.M. Leschene, M. Greenberg, J.R. Karr, M. Gochfeld, and C.W. Powers. 2003. Shifting priorities at the Department of Energy's bomb factories: protecting human and ecological health. Environmental Management 31(2): 157-167.

DHHS (U.S. Department of Health and Human Services). 1999. Biosafety in Microbiological and Biomedical Laboratories. Washington, DC: U.S. Government Printing Office.

EPA (U.S. Environmental Protection Agency). 1986a. Ambient Water Quality Criteria for Bacteria. Washington, DC: Office of Water. EPA440/5-84-002.

EPA. 1986b. Superfund Amendments and Reauthorization Act. [Online]. Available at: http://www.epa.gov/superfund/action/law/sara.htm.

EPA. 1997. Rules of Thumb for Superfund Remedy Selection. Washington, DC: Office of Solid Waste and Emergency Response. EPA 540-R-97-013.

EPA. 2000. Risk Characterization Handbook. Washington, DC: Science Policy Council.

Farkas, J. 1997. Physical Methods of Food Preservation. Pp. 497-519 in Food Microbiology: Fundamentals and Frontiers, M.P. Doyle, L.R. Beuchat, and T.J. Montville, eds. Washington, D.C.: ASM Press.

Fehner, T.R., and F.G. Gosling. 1996. Coming in from the cold: regulating U.S. Department of Energy nuclear facilities, 1942-96. Environmental History 1(2): 5-33.

GAO (U.S. Government Accounting Office). 1985. Cleaning Up Hazardous Wastes: An Overview of Superfund Reauthorization Issues. Washington, DC: U.S. General Accounting Office.

Havelaar, A.H., M.J. Nauta, and J.T. Jansen. 2004. Fine-tuning food safety objectives and risk assessment. International Journal of Food Microbiology 93: 11-29.

Henry, C.J., M.S. Moses, and R. Henderson. 1997. The need for policy and risk analysis - the Department of Energy experience. Toxicologic Pathology 25(1): 27-31.

Hoffman, F., A. Owen, I. Apostoaei, and B.A. Thomas. 2002. A perspective on public concerns about exposure to fallout from the production and testing of nuclear weapons. Health Physics 82(5): 736-748.

International Commission on Microbiological Specifications for Foods. 2002. Microorganisms in Foods 7: Microbiological Testing in Food Safety Management. New York: Kluwer Academic/Plenum Publishers.

IOM (Institute of Medicine). 2003. Scientific Criteria to Ensure Safe Food. Washington, DC: The National Academies Press.

Jones, C.R. 2004. A United States perspective on long-term management of areas contaminated with radioactive materials. Radiation Protection Dosimetry 109(1-2): 75-77.

Ledwidge, L., L.R. Moore, and L. Crawford. 2004. Stakeholder perspectives on radiation protection. Health Physics 87(3): 293-299.

Macler, B.A., and S. Regli. 1993. Use of microbial risk assessment in setting United States drinking water standards. International Journal of Food Microbiology 18(4): 245-256.

NRC (National Research Council). 1983. Risk Assessment in the Federal Government: Managing the Process. Washington, DC: National Academy Press.

NRC. 1994. Building Consensus Through Risk Assessment and Management of the Department of Energy's Environmental Remediation Program. Washington, DC: National Academy Press.

NRC. 1996. Understanding Risk: Informing Decisions in a Democratic Society. Washington, DC: National Academy Press.

O'Leary, H.R. 1997. DOE nurtures openness to mend past miscues. Forum for Applied Research and Public Policy 12(3): 103-108.

Sehulster, L., and R.Y.W. Chinn. 2003. Guidelines for environmental infection control—health care facilities. Morbidity and Mortality Weekly Report 52(RR10): 1-42.

Thomas, J.P. 2001. Rebuilding trust in established institutions. Health Physics 80(4): 379-383.

Till, J.E., and K.R. Meyer. 2001. Public involvement in science and decision making. Health Physics 80(4): 370-378.

Wentz ,C.A. 1989. Hazardous Waste Management. New York: McGraw-Hill.

4

Anthrax Decontamination After the 2001 Attacks: Social and Political Context

The question of when a facility is safe for reoccupation cannot be answered with physical data alone. Science provides highly sophisticated tools that help diminish uncertainties and, despite those uncertainties, help policy makers map out possible courses of action. However, the issue of safety goes beyond numerical calculations. The perception of what is safe ultimately depends on whether people believe what the technical experts and policy makers say about safety. The question, "How clean is safe?" is the same as, "What level of risk is acceptable?" Thus, if we are to build sensible policy recommendations, the physical and life sciences must work hand in hand with the social sciences.

This chapter discusses the social aspects of decontamination, using as case studies the major sites that were contaminated with *Bacillus anthracis* in fall of 2001. Four major cleanups resulted from the arrival of contaminated letters in the mail: the American Media, Inc. (AMI), building in Boca Raton, Florida; the National Broadcasting Company (NBC) offices in New York City; the U.S. Capitol Complex in Washington, DC; and two facilities of the U.S. Postal Service (USPS).[1] Remediation of the AMI and NBC buildings was done by private companies; government agencies led the remediation effort in the Capitol and USPS buildings. Separate entities controlled each contamination epicenter, and top decision makers gained varying degrees of stakeholder confidence for their health and safety pronouncements. A review of the four case studies reveals the

[1]Other places, including an American Broadcasting Company mailroom, also were contaminated but the committee did not review information on these locales.

ways the larger social, economic, and political context affects how human health risk is defined, remedied, or contested. Another perspective on the anthrax attacks of 2001 can be found in P.S. Brachman's thorough commentary, *Bioterrorism: An Update with a Focus on Anthrax* (2002).

UNCERTAIN SCIENCE, CERTAIN SOCIAL DIVISION

A successful decontamination project will require the following:

- Removal of the threatening agent to the greatest extent feasible.
- Certification that the property is as safe as it was before contamination occurred.
- Public or stakeholder acceptance of the credibility of those who have certified the safety of the property.

Those three elements are both technical and social, and they are all difficult to achieve. But without all three elements, in the case of a real-world decontamination effort, the answer to "How clean is safe?" would likely be, "Cleaner than you claim."

Consider, for example, the hypothetical situation of an anthrax contamination of a major metropolitan airport, San Francisco International (SFO). Decades of practical work in decontaminating laboratories at Fort Detrick, Maryland, and elsewhere, demonstrate convincingly that cleanup and reoccupation of buildings are achievable. But even if those same techniques used at Fort Detrick were applied at SFO, at the end of the project, someone must say, "It is safe to go back into the airport."

Were that announcement marred by uncertainty about residual contamination, or about the decision-making process regarding safety, it is unlikely that SFO would reopen. If decision makers stated that scientists *think* they *may* have decontaminated SFO, stakeholders would not likely be convinced that the airport is safe. And yet, officials would not be able to claim with certainty that no spores remained after cleanup. "Zero spores," after all, is an undetectable quantity. Policymakers must be able to state, with credibility and defensibility, that they have used the most conservative science available and that they have used proven decontamination techniques (Hsu et al., 2002). Decision makers also will need the public to see their decisions as legitimate. Legitimacy can not be commanded, and it does not flow automatically from competent science.

No Universal Definition of Health Risk

There is no documented threshold for cleanup of *B. anthracis*—especially in its weaponized form—below which no health effects would occur. Raber and colleagues (2003) noted that uncertainties surrounding *B. anthracis* contamina-

tion, such as its persistence and LD_{50}, present considerable difficulties in defining the amount of cleanup possible. And they note that "it is important to emphasize that decontamination and cleanup issues are not only agent-specific, but scenario-dependent and site-specific as well." Similarly, an NRC report (1996) noted that "the appropriate level of effort for a risk characterization is situation specific." The implication for this committee's task is that the committee can provide general guidance about when a facility is safe for reoccupation, but it cannot provide a recipe for every eventuality.

Raber and colleagues (2004), summarizing a report by the U.S. Government Accounting Office (GAO), also brought special attention to the issue (p. 38):

> First, there is now consensus among experts that even a few anthrax spores could be harmful to a susceptible individual. Second, according to officials from the US Army Medical Research Institute of Infectious Disease, what is most important is not the number of spores in a facility, but whether or not any spores are found. Finally, the unpredictability of the lethality of anthrax, the broad spectrum of population potentially at risk of exposure, and the inability to determine the route that contaminated mail might take as well as the extent of cross contamination make it ". . . extremely difficult to establish the health risks associated with a release of a biological agent, such as anthrax."

Analytic-Deliberative Process to Identify Health Risk

A previous NRC report on risk assessment states "it is necessary to reconceive risk characterization in order to increase the likelihood of achieving sound and acceptable decisions" (NRC, 1996). That report conceived of risk characterization as more than a specification of technical inputs. It recommended "a combination of analysis and deliberation" which it called the analytic-deliberative process, as a way to create and provide information about risk that would

> . . . describe a potentially hazardous situation in as accurate, thorough, and decision-relevant a manner as possible, addressing the significant concerns of the interested and affected parties, and to make this information understandable and accessible to public officials and to the parties.

That committee also noted that when the stakes are high but public trust in responsible organizations is low, "the organization may need to make special efforts to ensure" that risk decision processes are seen as legitimate by affected parties. "Adequate risk analysis and characterization thus depend on incorporating the perspectives and knowledge of the interested and affected parties from the earliest phases of the effort to understand the risks" (NRC, 1996). The report noted that the analytic-deliberative process should incorporate scientifically rigorous analysis with the perspectives and knowledge of the interested and affected parties. "The process must have an appropriate diverse participation or represen-

tation of the spectrum of interested and affected parties, of decision makers, and of specialists in risk analysis, at each step."

In testimony before the U.S. House of Representatives, Myke Reid drew attention to problems of cost, noting that "huge costs and delays have sometimes resulted when a risk situation was inadequately diagnosed, a problem misformulated, key interested and affected parties did not participate, or analysis proceeded unintegrated with deliberation" (Reid, 2003). Such conditions would likely hold in a future biocontamination of a public facility. But it need not be so. Tools such as the decision-making framework outlined in Chapters 11 and 12 can lower the probability that such trouble would ensue.

CASE STUDY SELECTION

Case studies can be used to illuminate the social aspects of a decontamination project. Along with extant research on risk communication and disaster response, case studies provide lessons learned—both positive and negative. As this committee explicates the case studies, it is not passing judgment on decision makers or decisions. The choices were often difficult, and they occurred in fast-moving and highly uncertain technical and political environments. The cases provide a range of examples for leadership, risk communication, and risk dilemmas. The point is not to blame but to use available knowledge to address the important question of what constitutes an acceptable level of cleanup for safe reoccupation of a facility.

The anthrax attacks in the fall of 2001 (the major milestones are chronicled in Box 4-1) resulted in extensive contamination of several facilities. But even in locations where the contamination was relatively contained, substantial disruption resulted. The amount of *B. anthracis* in two letters—one addressed to Senator Patrick Leahy (D-Vermont) and one to Senator Thomas Daschle (D-South Dakota)—has been estimated at 1-2 grams (D. Canter, EPA, presentation to committee, November 24, 2003). The total cost of decontamination of the affected buildings on Capitol Hill in Washington, DC, apparently cannot be estimated. "Capitol Hill anthrax-related cleanup cost for all 30 sites is estimated to be about $27 million by EPA. A total cost estimate for the Brentwood and Trenton facilities of about $200 million is probably an underestimate. The estimate for stripping and fumigation alone at the State Department to date is about $10 million" (D. Canter, EPA, presentation to committee, November 24, 2003). Chapman and Leng (2004) report that "almost $1 billion [was spent] to test for, remediate, and prevent anthrax contamination." Despite the lack of solid information about the total cost, two conclusions can be made confidently: The costs were high and, in some cases, unnecessarily so because there was not enough accurate information available about the buildings themselves or about how to proceed. Accurate floor plans, for example, and validated protocols for sampling were not available at the start of the process (Schaudies and Robinson, 2003).

BOX 4-1
Chronology of Key Events Following the Attacks

October 2, 2001—An infectious disease physician recognized a possible case of inhalational anthrax in a man hospitalized in Palm Beach County, Florida. This physician contacted the local health officer in Palm Beach County, who immediately began a public health investigation. By October 2, there were already 7 persons with cutaneous anthrax in the northeastern United States, but none had yet been diagnosed.

October 4—The microbiologic diagnosis of *B. anthracis* was confirmed by the Florida Department of Health and the Centers for Disease Control and Prevention (CDC), and the diagnosis was made public. Epidemiologic and environmental investigations were launched to determine the source of the patient's anthrax exposure. Evidence of contamination with *B. anthracis* was found at American Media Inc. (AMI) in Boca Raton, Florida, where this first victim worked as a photo editor.

October 5—The first victim of the anthrax attacks died. A second AMI employee, who had been hospitalized for pneumonia on September 30, was diagnosed with inhalational anthrax. He was an employee in the AMI mailroom.

October 6—The Palm Beach County Health Department began to obtain nasal swabs from those who had been in the AMI building in an attempt to define exposure groups. Because nasal swab testing was known to be an insensitive diagnostic test, the health department also recommended prophylactic antibiotics for all those people who had been in the AMI building for at least 1 hour since August 1 regardless of the results of their nasal swab tests. Environmental samples taken from the mailroom showed evidence of *B. anthracis*.

October 7—A nasal swab was positive on another employee. A swab from the first victim's computer screen was positive. The AMI building was closed.

October 9—The New York City Department of Health notified CDC of a woman with a skin lesion consistent with cutaneous anthrax. The woman, an assistant to NBC anchor Tom Brokaw, had handled a powder-containing letter postmarked September 18 at her workplace.

October 13—Another cutaneous case of anthrax was recognized in a 7-month-old infant who had visited his mother's workplace, the ABC office building on West 66th Street in Manhattan, on September 28.

October 13—Symptoms of cutaneous and inhalational anthrax in New Jersey postal workers began to be observed and reported by physicians to the New York City Health Department. Diagnoses of anthrax are confirmed by the CDC on October 18 and 19.

October 15—A staff member in the office of Senator Daschle in the Hart Senate Office Building opened a letter (postmarked October 9) which contained a powder and a note identifying the powder as anthrax. The powder tested positive for *B. anthracis* on October 16. Nasal swab testing of anthrax spores was performed on 340 Senate staff members and visitors to the building who potentially were exposed and to approximately 5,000 other people who self-referred for testing. This testing indicated exposure in 28 persons. Antimicrobial prophylaxis was administered on a broader scale and environmental testing was initiated.

October 19—CDC linked the four confirmed cases of anthrax to "intentional delivery of *B. anthracis* spores through mailed letters or packages."

October 19-22—Four postal workers at the Brentwood Mail Processing and Distribution Center in the District of Columbia were hospitalized with inhalational anthrax. The Brentwood facility was closed on October 21. On October 22 two of these four postal workers died.

October 24—CDC sent an advisory to state health officials via the Health Alert Network recommending antibiotic prophylaxis to prevent anthrax for all people who had been in the non-public mail operations area at the USPS's Brentwood Road Postal Distribution Center or who had worked in the non-public mail operations areas at postal facilities that had received mail directly from the Brentwood facility since October 11.

October 27—A CDC alert recommended antibiotic prophylaxis for workers in the mail facilities that supplied the CIA, the House office buildings, the Supreme Court, Walter Reed Army Institute of Research, the White House, and the Southwest Postal Station after preliminary environmental sampling revealed *B. anthracis* contamination in these mailrooms.

October 31—A 61-year-old female hospital stockroom worker in New York City died from inhalational anthrax after she had become ill with malaise and myalgias on October 25. The source of her exposure remains unknown despite extensive epidemiologic investigation.

November 16—A 94-year-old woman residing in Oxford, Connecticut, was hospitalized with fever, cough, and weakness. She died on November 19. Her diagnosis was confirmed as *B. anthracis* on November 20 by the Connecticut Department of Public Health Laboratory. Subsequent environmental and epidemiological testing indicated exposure from cross-contaminated letters.

Reprinted from Gursky et al., 2003.

Cost, however, might not be the major consideration in the decontamination of a public transportation facility. There is no economic justification that would overcome the perception that such a facility has been poisoned with weaponized anthrax. Chapman and Leng (2004), on considering a contamination event at SFO, say, "One year of cleanup (shutdown) would translate to 6-10 years for recovery of the airport….With preplanning, it might be possible to reduce the time from years to months." Given the significant capital investment an airport complex represents and its role in the overall national economy, decision makers might expend extremely large amounts of money to avoid the permanent loss of an airport.

American Media, Inc.

The AMI building in Boca Raton, Florida, was the first in which *B. anthracis* spores were detected in the fall of 2001. The contamination was extensive, and the building remained contaminated until July 2004. Details of the receipt of a letter containing a white powder were obtained in retrospective interviews the Federal Bureau of Investigation (FBI) conducted with AMI employees, but the letter was never found. In fact, during interviews with employees, it was speculated there might have been a second letter or a package that contained white powder. It was not until Robert Stevens, an AMI employee, became ill, was hospitalized and subsequently diagnosed, and died of anthrax that government officials began to test areas where Mr. Stevens lived and worked. Places he shopped and the areas he fished also were tested.

Stevens was hospitalized October 2, 2001. His diagnosis of inhalational anthrax was announced on October 4, 2001. The next day, U.S. Department of Health and Human Services Secretary Tommy Thompson announced that the case was "isolated." New York City Mayor Rudolph Giuliani told New York residents that they should not be concerned. Thompson also said, "We do know that he drank water out of a stream when he was traveling to North Carolina last week" (CNN, 2001). Those overconfident pronouncements were unwarranted and are recognized as the kind of statements that lead to mistrust of officials and experts (Freudenburg, 1993). A team from CDC traveled to North Carolina to test areas Stevens had visited the previous week. In addition, in an effort to determine the possible source of the infection, those close to Stevens were interviewed (Cole, 2003).

Medical practitioners involved with Mr. Stevens's care notified state health officials as soon as they suspected inhalational anthrax. Local health authorities quickly took action to mobilize a response team without waiting for confirmatory testing from CDC. The team alerted health care providers at area hospitals to signs and symptoms of anthrax, which possibly led to the diagnosis of a second case of inhalation anthrax in Florida. The response team set up a telephone hotline for persons who believed they had been exposed, and a website was

created to address questions from the public about anthrax. The AMI case also led to the initiation of a large-scale postexposure prophylaxis program (Heyman, 2002).

Initial sampling of the AMI building was carried out primarily by the FBI, which sought forensic evidence. A response team from CDC also was sent to quantify the building's contamination. Two weeks after the initial investigation began, EPA took over the lead in collecting samples from the building. Sampling was performed to track contamination in the building so that remediation recommendations could be made to the building's owner. A plan delineating sampling procedures in response to a biothreat may be similar to epidemiological sampling strategies, but those actions had not been performed on a large scale with *B. anthracis* until the AMI case. The CDC sampling team initially collected samples primarily from the mailroom and from Stevens's office to quantify contamination in those areas (K. Martinez, CDC, presentation to committee, November 24, 2003).

By the time the U.S. Environmental Protection Agency (EPA) began to collect samples, it was obvious from the results of previous FBI and CDC testing that the AMI building was highly contaminated with *B. anthracis* spores. EPA used blueprints of the building to identify areas for collecting samples from various surfaces. Samples were taken primarily using wipe and HEPA vacuum sock methods. Those samples eventually helped to determine the method of decontamination to be used. During the summer of 2002, CDC and the FBI returned to the AMI building to collect additional samples (K. Martinez, CDC, presentation to committee, November 24, 2003).

In July 2004, the AMI building was declared to have been successfully decontaminated. There are lessons from the case that could be applied to a contaminated public transportation facility, but some of the specifics of the AMI example are unusual and would likely not apply to our hypothetical future case. The AMI case raises the possibility that a contaminated building could be abandoned and that nobody would take responsibility for its remediation. It is also an example of a remediated building no longer in use for its original purpose: AMI employees relocated in 2001. The AMI building is smaller than the other facilities that had to be decontaminated. Most important, decontamination experts had 3 years to plan their procedures. All of those factors limit the lessons from the AMI case, because none of them is likely to operate if a large public transportation facility were to be contaminated with *B. anthracis*.

There are, nonetheless, several interesting observations to make. The AMI building cost "significantly less than $5 million" to decontaminate (J. Mason, Sabre Technical Services, presentation to committee, October 13, 2004) and the decontamination effort was a technical success. Extensive sampling done throughout the building after decontamination showed that "the 'no growth' standard for all environmental samples was achieved as a result of the fumigation" (Sabre Technical Services, 2004). The standard was no growth to an 8 log kill, and the

company responsible for the cleanup demonstrated its results with about 2000 spore strips. The AMI building experience also demonstrates the utility of having clearly established lines of responsibility for decontaminating a facility. The vendor—anticipating the need to explain how a successful cleanup was validated—used three-dimensional graphic software to track the sampling database, making an otherwise complex endeavor readily understandable to a nontechnical audience.

The committee was told (J. Mason, Sabre Technical Services, presentation to committee, October 13, 2004) that although the compressors were turned off, the air conditioning was left running at the AMI building for 2 years, and that the air inside the building was probably exchanging with the outside air "four times a day." Greater control of the building and its contaminants was instituted after a responsibility for decontamination was clearly established.

National Broadcasting Company

A letter tainted with *B. anthracis* arrived at NBC on September 19, 2001. Two cases of cutaneous anthrax were later identified there—one of them in an NBC employee who tested positive for cutaneous anthrax on October 12, 2001. There was extensive destruction of the physical plant at NBC. Contaminated areas included the Nightly News set, the mailroom, and a security office. A decision was reached early to evacuate the third floor, where the news operation is located. Extensive sampling was conducted above and below the third floor: 1200 employees were tested with nasal swabs; the test was administered to all employees who requested it (J. Eck, NBC, presentation to committee, March 29, 2004).

NBC officials concluded that one "can't do enough communicating" and that "even if [they] found one spore" they would continue to decontaminate (J. Eck, NBC, presentation to committee, March 29, 2004). NBC management said it wanted to be able to "say with a straight face to our employees that we sampled until we found no more spores." NBC also communicated to its employees through the behavior of upper management. Managers "made sure [they] went down and ate at the commissary" to demonstrate that it was safe to eat there. Indeed, managers said they "sought out people's opinions not only by walking around but all email was responded to" and that was a major reason there was "no panic at any point." Although NBC seems to have inspired considerable confidence in its employees, no research effort was conducted to assess employee concern.

Because there were no guidelines to follow regarding what constituted adequate cleanup, a "cross section of employees were involved in management of the crisis." Personnel from different departments were involved in making critical decisions. Management believes that involvement helped build trust through-

out the organization. In all, 1200 employees were tested with nasal swabs, and all tests were negative. Of course nasal swabbing is a not diagnostic tool, so its utility in the NBC case was a way to communicate to employees that the company was competent to perform during the crisis.

New York City Department of Health and Mental Hygiene officials believed that NBC management went overboard (J. Prud'homme, NYCDOHMH, presentation to committee, January 28, 2004), "setting a standard not every company could live up to." "When in doubt we gutted," was the decontamination principle employed by NBC corporate leadership (J. Eck, NBC, presentation to committee, March 29, 2004). NBC set an explicit policy that it would continue sampling until no *B. anthracis* was detected. Yet management did not promise that every spore was gone. No unconditional guarantee was offered or demanded.

The NBC case is an apparent success story, both technically and socially, but there are limits to the conclusions it supports. The committee's information on this case came exclusively from two NBC managers and from a city health official responsible for overseeing the restoration effort. Requests from committee staff and from a committee member for interviews with a wider range of NBC employees were not responded to positively. The committee asked NBC managers how they knew that employees were satisfied with the decontamination, and it was told that the lack of complaints was indicative of the acceptability of risk.

Nevertheless, the NBC response appears to have involved transparency in decision making, constant communication of information to stakeholders, involvement of affected parties in deciding policy, and a commitment to additional cleaning if contamination was discovered. The goal would be zero spores, the committee was told. That would seem important both as a technical goal and as a commitment to health and safety on the part of management.

Capitol Complex

There was an extensive search for *B. anthracis* contamination in more than two dozen government buildings in Washington, D.C. The uncertainties were much greater than those at NBC and AMI, although they were similar to those faced by the USPS. There were more stakeholders involved and there was more attention from the media. There also was a pressing need, or a perceived pressing need, to reopen the buildings quickly. According to the EPA's Federal On-Scene Coordinator's (FOSC) Report, "The Capitol Hill Site initially consisted of 26 buildings with suspected anthrax contamination. All 26 buildings were sampled; anthrax was detected in seven buildings, all of which were decontaminated and cleared for re-entry after confirmation sampling" (EPA, 2002). It was a massive effort, involving more than 50 organizations. "Trillions" of anthrax spores were removed in the decontamination (EPA, 2002). Those seven buildings were:

P Street Warehouse
Supreme Court Building
Dirksen Building
Ford Building
Hart Building
Longworth Building
Russell Building

The committee did not review the decontamination effort for each building but the official decontamination standard was the same for each building: Extensive sampling should show that there was no spore growth. In each case there was no significant conflict among stakeholders about when or whether to return a building to operational status. To some degree, that represents a risk communication success. However, there were different procedures for certifying that buildings could be reoccupied, and there was no coherent, organized entity that oversaw decontamination throughout. That organizational failure likely added to the uncertainties, costs, and length of time that buildings were closed. A more coordinated response would have increased efficiency and effectiveness. The FOSC report notes that "no single entity" would accept responsibility for reoccupying the buildings after decontamination (EPA, 2002). It also noted that CDC "left the site after the first few weeks" and did not return until the end of the decontamination. There is obviously a need for clear lines of responsibility in any decontamination effort. It seems likely that the cleanups at the Capitol complex would have gone more smoothly had there been a broader understanding of responsibilities.

Some "20 to 130 initial samples collected in each building" were initially taken in the 26 buildings. Overall, EPA spent about $27 million "to clean up anthrax contamination on Capitol Hill, using funding from its Superfund program" (EPA, 2002). The steep expenses incurred seemed to result from several factors. The high-profile users of the buildings undoubtedly created pressure to reopen the buildings quickly, yet a conservative definition of "clean" was adopted by EPA. More important, there was a lack of a standard protocol to drive remediation, which in some cases led to repeated decontamination.

The *B. anthracis* crisis in Washington, D.C., started on October 15, 2001, on the 6th floor of the Hart Senate Office Building (HSOB), when a Senate staff member opened an envelope addressed to Senator Tom Daschle. Senate staff had been trained to be alert for *B. anthracis*, so they knew the procedure. The Capitol Police were on the scene within minutes, soon followed by the force's hazardous device unit (Hsu et al., 2002). On-the-spot tests gave positive indicators for *B. anthracis* within 15 minutes. The ventilation system was shut off about 45 minutes after the initial discovery of the contamination. Medical staff immediately collected nasal swabs from those most likely to have been exposed, and they initiated antibiotic prophylaxis. Within 9 hours of the initial exposure, everyone

in the office suites of Senator Daschle and Senator Russell Feingold (D-Wisconsin) and official responders had been tested with a nasal swab (Hsu et al., 2002).

EPA was notified on October 16 and the building was closed on the evening of October 17. Over the next three days, nasal swab samples were collected from all HSOB employees and from anyone else on Capitol Hill who requested it (Hsu et al., 2002). One report in the *Journal of the American Medical Association* reported that more than 7000 nasal swabs were analyzed (Weis et al., 2002). Everyone tested was given antibiotic prophylaxis, pending test results. CDC arrived on October 16 and defined "the population at risk…as persons in the exposed area during or after the time the contaminated envelope was processed or opened" (Hsu et al., 2002). Other organizations, including EPA, the U.S. Coast Guard, FEMA, FBI, and the National Institute of Occupational Safety and Health, were also involved in the response: "The incident response involved coordination of more than 50 organizations" (Schaudies and Robinson, 2003). The situation at the Hart Building and other contaminated buildings was unprecedented and confusing. Initially, some expected the entire building to be decontaminated. Later it was decided that by following the mail trail, only those parts of the building that were sampled and found to be contaminated would be treated (D. Canter, EPA, presentation to committee, November 24, 2003).

EPA defined the acceptability of the Hart Building cleanup as zero *B. anthracis* growth on any samples taken. The standard was not zero *B. anthracis*, which is impossible to demonstrate. To ensure credibility, EPA took a large number of samples and, according to Raber and colleagues (2003) "verbally indicated that essentially all surfaces in the Hart Building were swabbed." Faced with unprecedented problems at HSOB, the determination was made that there was no acceptable level of *B. anthracis* spores that could remain in the building (D. Canter, EPA, presentation to committee, November 24, 2003). "Cleanup" therefore was defined as no detectable growth of *B anthracis* spores in any sample. HSOB reopened on January 22, 2002.

In a report available from the Office of Pesticide Programs at EPA, Schaudies and Robinson (2003) note that numerous problems with the information available to facilitate the response in the Capitol complex—problems that included inaccurate floor plans, nonexistent protocols for sampling, long hours, and constant strain:

> . . . the sampling and remediation activities were successful overall based on the fact that all clearance samples showed no growth in any areas previously contaminated with *B. anthracis*. In addition, no one has presented with symptoms of anthrax since buildings on Capitol Hill were remediated and cleared for reoccupancy. This is clearly the best measure of the success for the response and remediation activities . . . Over 9,000 samples were collected throughout the course of the response.

From available documents and presentations to the committee, it is apparent that many things went right on Capitol Hill in the fall of 2001. But there were problems, too, and any future decontamination effort can benefit from attention to them. The Capitol Hill response was uncoordinated, and it was marked by inconsistencies, especially concerning the closing of buildings. It does not appear that the Supreme Court building was closed at all, even though *B. anthracis* was found there. The contaminated letter was opened in the Hart Building on October 15, but the building was not closed until 2 days later on October 17. The Longworth Building was closed that day, and most of it was reopened three weeks later on November 5 (EPA, 2002). The Ford Building was closed October 20, as was the Dirksen Building. The P Street Warehouse, a mail facility, was never closed, even though *B. anthracis* was found in several places within it. The Russell Building was closed on October 20, and then again on November 17, and then decontamination occurred.

There were two sign-off procedures for the Capitol complex. The Dirksen Building and the Supreme Court were certified "informally," in the words of the FOSC's report (EPA, 2002). The certification was done by circulating a "sign-off" sheet between the Incident Commander, a contractor, and the attending physician. The same process was used for parts of the P Street Warehouse and the Russell Building. Later, a more thorough process developed that increased the number of agents to sign off on decontamination.

One result of the uncoordinated response was a haphazard decontamination standard. EPA initially had "set a criterion of zero spore growth for determining whether decontamination had been successful in each building. However, no frame of reference existed for such a criterion. The meeting between CDC and EPA concluded that best professional judgment should be used in reviewing the data to determine when the remaining buildings were ready for reoccupation" (EPA, 2002).

An effective response to hazardous situations requires decision-making transparency, coordinated decisions, and meaningful risk communication. Every action that officials and organizations take is fraught with communicative import. Consider nasal swabbing: Nasal swab sampling for *B. anthracis* is not diagnostically useful. It was known in the fall of 2001 that, indeed, some experts argue that it is a complete waste of resources to conduct massive nasal swab testing. But the extensive sampling likely conveyed the message that the hazard that building occupants might face was being taken seriously.

It is important to remember that all official actions have meaning beyond their instrumental utility. For example, on Capitol Hill extensive efforts were made to provide antibiotic prophylaxis. Such actions are medically useful—there likely would have been more discovered cases of anthrax absent such prescription. But the action also sent the message that people's concerns were valid.

United States Postal Service

Because the *B. anthracis* traveled through the postal system, several USPS facilities—although the precise number is not clear—were contaminated with weaponized *B. anthracis*, some more extensively than others. The Hamilton Processing and Distribution Center in Trenton, New Jersey, and the Brentwood Processing and Distribution Center in Washington D.C. (later renamed Curseen-Morris Processing and Distribution Center to honor the men who died from anthrax) experienced extensive contamination. Another postal facility, in Wallingford, Connecticut, was the route through which contamination reached a citizen in Oxford, Connecticut. There were two cases of anthrax at Hamilton, four at Brentwood with two deaths, and one death in Connecticut. All of the deaths were from inhalational anthrax.

The contaminated envelopes addressed to Senators Tom Daschle and Patrick Leahy entered the mail stream at Hamilton on October 9, 2001 and Brentwood on October 11, 2001. The Wallingford facility was most likely cross-contaminated by mail sent from Hamilton. The doses to which people were exposed are not known, but the doses are presumed to have been higher among postal workers than among other people.

The technical problems of detection and decontamination at USPS facilities were similar to those at the Capitol complex, although the volume of space at Hamilton and Brentwood that required decontamination was considerably larger. According to the *Morbidity and Mortality Weekly Report,* on October 18, 2001, a "postal service contractor" took 29 samples from the mail sorting area at Brentwood (CDC, 2001). CDC initiated its own investigation there on October 20. The fate of the original 29 samples taken by the USPS contractor is not clear. Dewan and colleagues (2002) indicate that the first inhalational anthrax case at Brentwood was diagnosed on October 19 and confirmed on October 21. Also on October 21, postal worker Thomas Morris, Jr., was diagnosed with anthrax (he died later that night). Brentwood was closed that day. Nasal swab samples were taken from Brentwood employees and from people who visited the facility between October 10 and October 21, for a total of 3110 people (Dewan et al., 2002). Seventy-eight percent of Brentwood employees were given antibiotic prophylaxis (1870 of 2403) (Dewan et al., 2002).

There seems to have been difficulty identifying *B. anthracis* at the Wallingford postal facility. Counter to CDC recommendations, initial sampling by USPS was done with dry wipes; that effort yielded no positive samples. After four attempts, the last two using wet wipes and HEPA vacuums, mail-sorting machines were found to be contaminated (GAO, 2003). From the final samples, taken on November 28, two results were provided by the CDC-contracted laboratory. One was "about 3 million colony forming units (CFUs) of anthrax (that is, 5.5 million CFUs per gram of dust) in a sample collected from a heavily contaminated mail-sorting machine." Decontamination of the machines began on Decem-

ber 2. According to GAO (2003), "when anthrax contamination was first identified [at Wallingford, on December 2, 2001]—USPS met with workers to inform them that 'trace' amounts of anthrax had been found in the samples collected on November 28." The phrase "trace amount" was used apparently on advice of the chief epidemiologist for the state of Connecticut. On December 21, 2001, district managers told workers there was a "concentration" of spores in a sample. The more quantitative information was not conveyed to workers until 9 months later.

It is generally thought that USPS management could have communicated more effectively with employees about decisions and procedures for nasal swabbing, antibiotic prophylaxis, and decontamination. Comparing their experience with events at the Capitol complex, some USPS employees expressed the belief that their concerns were not taken seriously. The Hart Building had been closed quickly, thousands were immediately put on antibiotic prophylaxis, and nasal swabbing was used extensively. By contrast, USPS facilities were not closed until there were official diagnoses of anthrax, the recommended dosage of antibiotics was different for employees in the two places, and nasal swabbing was more limited at the postal facilities than it had been on Capitol Hill.

Such differences were taken by some USPS employees as symbols that their concerns were not as important as were those of Capitol complex employees. Additionally, all four anthrax cases at Brentwood were among African Americans, which contributed to a perception among some that race was important in attending to the crisis. The committee does not believe that race was a factor in the deliberations, but such perceptions clearly can be important in establishing trust among stakeholders.

It was quickly known that *B. anthracis* had contaminated the Daschle suite in the Hart Building because people saw the powder and it was analyzed immediately. This was not the case at any of the postal facilities. At the time, the prevailing assumption was that *B. anthracis* could not escape from a taped envelope. By the time officials realized that postal facilities were contaminated with *B. anthracis* it was generally too late to employ nasal swabs as a means of assessing the extent of contamination. It is clear that there were some behavioral and perceptual issues regarding the postal service contaminations. It is not this committee's task to research those issues in great detail. It is, however, this committee's task to glean lessons from available evidence regarding acceptable risk. Judging from that evidence, and projecting a *B. anthracis* attack on a public transportation facility, the committee has concluded that risk acceptability would be enhanced to the extent that trust is fostered between labor and management and to the extent that decision making about important issues includes those who might bear the brunt of decisions about risks.

There are two important limitations in this discussion about the *B. anthracis* contamination at USPS facilities. First, the committee heard no direct testimony from postal workers. Second, although the committee requested decontamination data from the USPS, those requests were not responded to positively.

CONCLUSIONS

The events of the fall of 2001 provide several valuable lessons. Before those incidents it was not known that cross-contamination with *B. anthracis* can be a significant risk. Although it was thought that 8000 to 10000 anthrax spores are needed to infect someone, this is an average figure and some people may be infected at much lower doses. The spread of *B. anthracis* was thought to be unlikely from a closed envelope. We now know that not only can *B. anthracis* escape from an envelope but that it can subsequently spread throughout a facility (Kournikakis et al., 2003).

The committee has heard from several sources that the needs of law enforcement and public health agencies sometimes do not coincide, and that the lack of concordance can hinder effective responses to a crisis. The committee concurs with the opening sentence of a recent agreement signed by law enforcement agencies and the New York City Department of Health: "In the event of a suspected or confirmed bioterrorist ("BT") event, it is essential that public health and law enforcement agencies coordinate their investigations closely, so that shared objectives (e.g., determining where and when a release may have occurred) can be reached" (NYDOHMH, 2004).

The committee itself encountered organizational resistance to complete sharing of relevant data. Notable in this regard is a conclusion reached by the 9/11 Commission regarding the other terrorist attacks of 2001: "The culture of agencies feeling they own the information they gathered at taxpayer expense must be replaced by a culture in which the agencies instead feel they have a duty to inform the public" (NCTAUS, 2004).

The anthrax response and subsequent decontamination experiences provide several lessons. The acceptance of risk is likely to be enhanced if trust is fostered and preserved among authorities, subject matter experts, and affected parties; if decision making about key issues includes those who must bear the brunt of the consequences of those decisions; if affected populations see—because of transparent decision making—that their health and safety are given higher priority than material considerations, such as disrupted work schedules and cleanup costs; if the complex technical dimensions of the problem are translated into terms that are meaningful to nontechnical audiences; and if constant and open communications is maintained between responsible officials and directly and indirectly affected parties.

FINDINGS AND RECOMMENDATIONS

Finding 4-1

Acceptability is not a technical concept. It is a values concept. It is, therefore, best constructed through an analytical and deliberative process that involves key stakeholders in a potentially harmful situation. Without trust, acceptability is difficult

to achieve. Effective leadership in dangerous situations is based on openness and honesty, even when bad news must be conveyed. Transparency in decision making can contribute substantially to ensuring the acceptability of risk. Panic is rare in disasters, and it is an unhelpful idea for explaining how people respond to frightening situations and information. After the 2001 anthrax attacks, decision makers sometimes relied on assumptions that later proved unfounded; their subsequent actions resulted in significant problems with communicating the degree of risk involved to the stakeholders.

Recommendation 4-1

Risk managers who face potential contamination should assume that the problem could be worse than they initially think. In remediation projects, the public should be seen as an asset, not a liability, and information should be made available widely. Indeed, the public should participate actively in decision making in the aftermath of an attack. Following the lead of previous work by the National Academies, the committee recommends that an analytical deliberative process be used to determine appropriate approaches for cleanup.

Finding 4-2

Relevant data from the sites contaminated in 2001 were not shared with all necessary parties, partly because of the differing goals and objectives of law enforcement and public health agencies. Lack of data sharing can compromise health in the aftermath of a biological attack.

Recommendation 4-2

Agencies and organizations entrusted with data relevant to public health should make every effort to share this information. Cooperation is the key to decreasing public anxiety, and agreements, such as the one signed by the New York City Department of Health and relevant law enforcement agencies, should be in place to protect public health and safety by allowing the process of forensic evidence collection and decontamination to proceed unimpeded by one another.

REFERENCES

Brachman, P.S. 2002. Bioterrorism: an update with a focus on anthrax. American Journal of Epidemiology 155(11): 981-987.

CDC (U.S. Centers for Disease Control and Prevention). 2001. Evaluation of *Bacillus anthracis* contamination inside the Brentwood Mail Processing and Distribution Center—District of Columbia, October 2001. MMWR 50(5): 1129-1133.

Chapman, R.E., and C.J. Leng. 2004. Cost-Effective Responses to Terrorist Risks in Constructed Facilities. Gaithersburg, Maryland: National Institute of Standards and Technology. NISTIR 7073.

CNN. 2001. Florida anthrax case 'isolated'. [Online] Available at: http://archives.cnn.com/2001/HEALTH/10/05/florida.anthrax/.

Cole, L.A. 2003. The Anthrax Letters. Washington, DC: Joseph Henry Press.

Dewan, K., A.M. Fry, K. Laserson, B.C. Tierney, C.P. Quinn, J.A. Haslett, L.N. Broyles, A. Shane, K.L. Winthrop, I. Walks, L. Siegel, T. Hales, V.A. Semenova, S. Romero-Steiner, C. Elie, R. Khabbaz, A.S. Khan, R.A. Hajjeh, A. Schuchat, and the Washington, D.C. Anthrax Response Team. 2002. Inhalational anthrax outbreak among postal workers, Washington, D.C., 2001. Emerging Infectious Diseases 8(10):1066-1072.

EPA (U.S. Environmental Protection Agency). 2002. Federal On-scene Coordinator's Report for the Capitol Hill Site, Washington, D.C. EPA Region 3, Philadelphia, PA: GS-10F-0076K.

Freudenburg, W.R. 1993. Risk and recreancy: Weber, the division of labor, and the rationality of risk perceptions. Social Forces 71(4): 909-932.

GAO (U.S. General Accounting Office). 2003. Capitol Hill Anthrax Incident. Report to the Chairman, Committee on Finance, U.S. Senate: GAO-03-686.

Gursky, E., T.V. Inglesby, and T. O'Toole. 2003. Anthrax 2001: observations on the medical and public health response. Biosecurity and Bioterrorism 1: 97-110.

Heyman, D. 2002. Lessons from the Anthrax Attacks, Implications for U.S. Bioterrorism Preparedness: A Report on a National Forum on Biodefense. Defense Threat Reduction Agency Report.

Hsu, V.P., S.L. Lukacs, T. Handzel, J. Hayslett, S. Harper, T. Hales, V.A. Semenova, S. Romero Steiner, C. Elie, C.P. Quinn, R. Khabbaz, A.S. Khan, G. Martin, J. Eisold, A. Schuchat, and R.A. Hajjeh. 2002. Opening a *Bacillus anthracis*-containing envelope, Capitol Hill, Washington, D.C.: the public health response. Emerging Infectious Diseases 8(10): 1039-1043.

Kournikakis, B., S.J. Armour, C.A. Boulet, M. Spence, and B. Parsons. 2001. Risk Assessment of Anthrax Threat Letters. Defence Research Establishment Suffield: Technical Report, DRES TR-2001-048.

NCTAUS (National Commission on Terrorist Attacks Upon the United States). 2004. The 9/11 Commission Report. Washington, DC: Government Printing Office.

NRC (National Research Council). 1996. Understanding Risks: Informed Decisions in a Democratic Society. Washington, DC: National Academy Press

NYCDOHMH (New York City Department of Health and Mental Hygiene), NYPD (New York City Police Department), and FBI (Federal Bureau of Investigation). 2004. Joint Field Investigation Following a Suspected Bioterrist Incident. [Online] Available at: http://www.phppo.cdc.gov/od/phlp/docs/Investigations.PDF.

Raber, E., T.M. Carlsen, K.J. Folks, R.D. Kirvel, J.I. Daniels, and K.T. Bogen. 2003. How Clean is Clean Enough? Recent Developments in Response to Threats Posed by Chemical and Biological Warfare Agents. Livermore, California: U.S. Department of Energy Lawrence Livermore National Laboratory.

Raber, E., T.M. Carlsen, K.J. Folks, R.D. Kirvel, J.I. Daniels, and K.T. Bogen. 2004. How clean is clean enough? Recent developments in response to threats posed by chemical and biological warfare agents. International Journal of Environmental Health Research 14(1): 31-41.

Reid, M. 2003. Re-opening of the US Postal Service's Joseph Curseen, Jr. and Thomas Morris, Jr. Processing and Distribution Center. Testimony Before Committee on Government Reform, U.S. House of Representatives: October 23, 2003.

Sabre Technical Services. 2004. FIFRA Crisis Examption Final Report. Albany, New York: Sabre Technical Services, LLP.

Schaudies, R.P., and D.A. Robinson. 2003. Analysis of Chlorine Dioxide Remidiation of Washington, DC, *Bacillus anthracis* Contamination. McLean, Virginia: Science Applications International Corporation.

Weis, C.P., A.J. Intrpido, A.K. Miller, P.G. Cowin, M.A. Durno, J.S. Gebhardt, and R. Bull. 2002. Secondary aerosolization of viable *Bacillus anthracis* spores in a contaminated US Senate office. Journal of the American Medical Association 288(22): 2853-2858.

5

Framework for Event Management

The committee was directed to provide decision makers with practical advice about managing the final stages of decontamination and reoccupation of a facility after an act of bioterrorism. The case studies, field experience, and research outlined in Chapters 1-4 provide a basis for explaining how such an event might unfold and how various organizations and agencies have addressed real crises in public and private buildings. The succeeding chapters are meant to increase basic understanding about the specifics of buildings, the properties of biological agents that might contaminate buildings, and strategy for preparing for and managing events. The discussions concern risk assessment and risk management. Risk assessment involves identification and scaling of an event in terms of the biological agents involved and the effects on building systems and potentially exposed populations. Risk management broadly includes preparation, coordination, decontamination, clearance, communication, and medical monitoring.

This chapter introduces risk assessment and outlines the factors it should consider. Chapters 6-10 present some technical components of risk assessment and explain how characterization of the biological hazard, air movement in the building, dose–response modeling, sampling and identification of biological hazard, and decontamination methods used all contribute information to the assessment.

Chapters 5-10 lead to and support the discussions presented in Chapter 11, which offers decision makers guidance on response to and recovery from an act of bioterrorism. The committee recognizes there could be unforeseen circumstances or that some people might fill unfamiliar roles in an emergency. Laying out technical protocols will facilitate response in case of an attack. Developing

and practicing emergency plans and communication can lead to increased vigilance, security, and confidence among building occupants and can minimize anxieties during an event. We note that it is more likely that a building will have a flood, chemical spill, fire, or be subject to malodorous conditions, "sick building" problems, or disease clusters than that an attack with biological weapons will occur. The practical guidance offered here will have benefit if it is followed and applied to other untoward events that might occur.

Often, public health decisions (that result in regulatory or other actions) with respect to environmental exposures are made without complete knowledge. Some important factors often are not clear; others could be highly variable. A risk analysis methodology has been applied to environmental decision making in the United States over the past 20 years and by that approach, the estimated decreases in damage attributable to increasing regulation or control of exposure are balanced against the quantifiable, nonquantifiable, and noneconomic costs of an action to identify the most desirable decision. Although the metrics used to balance benefits and costs differ with the context, the overall process of assessing risks works the same way for many situations. The committee believes that the risk analysis framework is appropriate in the context of the question "How clean is safe?" for decontamination subsequent to the release of a biological agent.

A risk assessment that involves a microbiological pathogen—also known as quantitative microbial risk assessment (QMRA)—can follow the framework developed for assessing the risk attributable to exposure to harmful chemical agents as outlined by the National Research Council (NRC, 1983), and it broadly includes the following steps:

- *Hazard assessment* involves identifying pathogens, determining how exposure occurred, and assessing the potential outcomes of infection (course of disease). The vectors and vehicles for secondary transmission also are identified for transmissible agents.
- *Exposure assessment* evaluates the number of people who have ingested, inhaled, or otherwise been in contact with particular amounts (doses) of the infectious agents, and with what frequency.
- *Dose–response analysis* examines the relationship between the dose of biological agent to an individual person and the probability of that person's becoming ill. For populations, dose-response analysis characterizes the relationship between the dose of the agent in a given environment and the number of people who will become ill as a result of exposure to that agent in that place. Given a particular scenario for the distribution of doses and the associated uncertainties, the dose–response relationship provides an estimate of the expected number of adverse outcomes (disease cases) and their distribution and uncertainty.
- *Risk characterization* is a "synthesis and summary of information about a hazard that addresses the needs and interests of decision makers and of interested

and affected parties "(NRC, 1996). Risk characterization is a prelude to decision making that involves communicating information about the hazard to decision makers and interested and affected parties so that they have a comprehensive understanding of the risks, variables, and uncertainties. Those parties would become informed participants and share their perspectives and concerns in the risk characterization process.

- *Risk management* involves actions that should be taken to reduce the risks attributable to exposure to the biological hazard.

Using the terminology generally employed in the United States, *risk assessment* consists of the first four steps, and *risk analysis* encompasses risk assessment and risk management. Risk analysis includes policy and nonquantitative considerations, as described in other chapters of this report. Typically, a risk assessment is repeated several times for different management scenarios to determine the amount of remediation required to achieve a given reduction in risk. Risk assessment can be repeated for various degrees of remediation.

QMRA has been validated with several microorganisms:

- Dose–response information for ingestion of cysts of *Giardia lamblia* correlated with illness rates associated with waterborne contact (Rose et al., 1991)
- The attack rate during the massive waterborne outbreak of cryptosporidiosis in Milwaukee in 1993 matched projections from human dose–response information obtained from controlled human trials (Haas and Rose, 1994)
- An animal dose-response relationship for *Escherichia coli* O157:H7 was consistent with the attack rate noted in a recreational-waterborne outbreak (Haas et al., 2000)

QMRA has been used to formulate guidelines or standards in several contexts. A risk assessment approach was used in the development of the surface water treatment rule, which requires utilities that process surface water to demonstrate specific treatment results for reduction of *Giardia* and viruses before the water is distributed (Macler and Regli, 1993). Proposed rationales for treatment of wastewater for direct or indirect reuse have applied QMRA methodologies (Tanaka et al., 1998). After a series of international consultations, the World Health Organization proposed a unified framework for the control of infectious disease transmitted in water (potable, recreational, and agricultural) that has microbial risk assessment as an underlying paradigm (Bartram et al., 2001). The selection of respirators as personal protective devices against airborne infection has been analyzed with microbial risk assessment (Nicas and Hubbard, 2002). That was derived after validation with reference to airborne transmission of *Mycobacterium tuberculosis* (Nicas, 1996).

Alternative protocols also have been presented—for example, the schematic

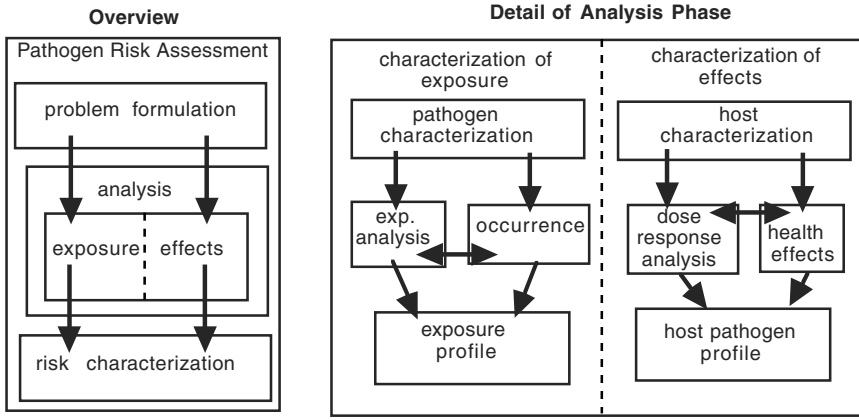


FIGURE 5-1 Schematic diagram of ILSI microbial risk analysis protocol. SOURCE: Adapted from ILSI, 2000.

protocol developed by the International Life Sciences Institute (ILSI) and shown in Figure 5-1 (ILSI, 2000). That protocol was based on the National Research Council framework (NRC, 1983) described above. It emphasizes the relationships between the technical and policy-making components of the risk assessment process, particularly at the problem formulation stage. It is designed to be useful for quantitative and qualitative risk assessments. As delineated by ILSI (2000), the process focuses on microorganisms in water, but much of it is relevant to the task of assessing harms caused by biological agents that could be released into public buildings or facilities. The first step is problem formulation, "a systematic planning step that identifies the goals, breadth, and focus of the risk assessment, [and] the regulatory and policy context of the assessment" (ILSI 2000). Figure 5-1 illustrates the second, or analysis, phase of ILSI's approach. It shows how a decision-making body would need to consider both pathogen and host characteristics and the surrounding environment to properly assess exposure and effects.

To understand the flow chart, one must evaluate the elements within each box. Several elements could be relevant to the risk analysis for a contaminated public transportation facility. They would be used to create an exposure profile:

- *Pathogen characterization* describes the virulence and pathogenicity of the microorganism, the diseases it cause, its survival and multiplication, its resistance to control or treatment, its host specificity, its infection mechanisms, its potential for secondary spread, and its taxonomy or strain variation.

- *Pathogen occurrence* identifies concentration, spatial distribution (including clumping, aggregation, particles, and clustering), nonhuman reservoirs, survival, persistence, indicators, and surrogates for indirect evaluation.
- *Exposure analysis* characterizes routes of exposure; the size and demographics of the exposed population; the spatial and temporal nature of exposure and whether single or multiple; the behavior of the exposed population; and treatment, processing, and recontamination.

The far-right-hand section of Figure 5-1 shows characterization of effects, which uses information from host characterization, dose–response analysis, and health effects to create a host–pathogen profile. ILSI's protocol contains several elements that are relevant to risk analysis for a contaminated public transportation facility.

- *Host characterization* describes the host population by age, immune status, concurrent illness, genetic background, pregnancy, nutritional status, demographics, and social and behavioral traits.
- *Health effects* are identified, including the duration and severity of illness, infectivity, morbidity, mortality, sequelae of illness, extent of amount of secondary transmission, and quality of life.
- *Dose–response analysis* is a statistical model that analyzes or quantifies dose–response relationships; human and animal dose-response data; use of outbreak or intervention data; route of exposure; source and preparation of material; organism type or strain, including virulence factors or other measures of pathogenicity; and characteristics of the exposed population.

The ILSI approach then pulls all of the relevant information together into a risk characterization that is subjected to two steps: risk estimation and risk description. That segment of the process would include characterization of uncertainty, variability, and confidence the decision-making group has in the estimates used above; sensitivity analysis to identify and evaluate the most important variables and information needs; and a decision analysis that evaluates alternative risk management strategies.

FINDINGS AND RECOMMENDATIONS

Finding 5-1

The QMRA process, developed over the past 20 years, has been used to inform decision making about events involving microbial hazards that affect food safety, drinking-water quality, and the use of isolation rooms in hospitals.

Recommendation 5-1

A risk assessment approach should be adopted as one component of decision making for determining the adequacy of decontamination efforts after a release or suspected release of a biological contaminant.

Finding 5-2

Thorough risk analysis requires critical information about each variable. This information is weak for certain variables when one considers agents that might be used in a biological attack.

Recommendation 5-2

More dose–response and sampling source data are needed to inform a practical, as opposed to a theoretical, risk analysis for any given biological attack.

REFERENCES

Bartram, J., L. Fewtrell, and T.-A. Stenstrom. 2001. Harmonised assessment of risk and risk management for water-related infectious disease: an overview. Pp. 1-16 in Water Quality. Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-Related Infectious Disease. L. Fewtrell and J. Bartram, eds. London: World Health Organization and IWA Publishing.

Haas, C.N., and J.B. Rose. 1994. Reconciliation of Microbial Risk Models and Outbreak Epidemiology: The Case of the Milwaukee Outbreak. Annual Conference—American Water Works Association, New York.

Haas, C.N., A. Thayyar-Madabusi, J.B. Rose, and C.P. Gerba. 2000. Development of a dose-response relationship for *Escherichia coli* O157:H7. International Journal of Food Microbiology 56(2-3): 153-159.

ILSI (International Life Sciences Institute). 2000. Revised Framework for Microbial Risk Assessment: An ILSI Risk Science Institute Workshop Report. Washington, DC: International Life Sciences Institute.

Macler, B.A., and S. Regli. 1993. Use of microbial risk assessment in setting United States drinking water standards. International Journal of Food Microbiology 18(4): 245-256.

Nicas, M. 1996. An analytical framework for relating dose, risk and incidence: an application to occupational tuberculosis infection. Risk Analysis 16(4): 527-538.

Nicas, M., and A. Hubbard. 2002. A risk analysis for airborne pathogens with low infectious doses: application to respirator selection against *Coccidioides immitis* spores. Risk Analysis 22(6): 1153-1163.

NRC (National Research Council).1983. Risk Assessment in the Federal Government: Managing the Process. Washington, DC: National Academy Press.

NRC. 1996. Understanding Risk: Informing Decisions in a Democratic Society. Washington, DC: National Academy Press.

Rose, J.B., C.N. Haas, and S. Regli. 1991. Risk assessment and the control of waterborne giardiasis. American Journal of Public Health 81: 709-713.

Tanaka, H., T. Asano, E.D. Schroeder, and G. Tchobanoglous. 1998. Estimating the safety of wastewater reclamation and reuse using enteric virus monitoring data. Water Environment Research 70(1): 39-51.

6

Hazard Identification and Assessment

Optimal decision making about decontamination procedures requires an accurate assessment of the problem. One of the first steps is proper identification of the agent or agents used in an attack. Initially, that can be done either by measurements at the putative site of release or by retrospective analysis that identifies the source using information gleaned from records of a medical case or cluster of cases. Additional information, such as the nature of the preparation and the extent to which contamination has spread, also helps with assessment. A critical parameter in any remediation effort is accurate characterization of the amount of contaminant present at the start of the decontamination.

At the Hart Senate Office Building in Washington, D.C., the source of the contamination was evident and localized: A white powder had fallen out of an envelope, and the amount was relatively easy to characterize. In contrast, the initial source of the *Bacillus anthracis* at the American Media, Inc. (AMI) building in Boca Raton, Florida, has never been identified, and those who carried out the decontamination had to sample the building extensively to identify areas of contamination. The *B. anthracis* found at the various postal facilities resulted from cross-contamination and was widely dispersed, not localized to a specific area.

The absence of a clearly identifiable source of contamination makes the process of containment and cleanup more complicated because the area to be surveyed must be more extensive. Identification of an actual amount of contaminant provides valuable information for the selection of a method of remediation. With the knowledge that one gram (g) of dried *B. anthracis* spores can contain up to 10^{12} spores, a facility contaminated with 10 g requires substantially more than

a six-log kill. (Six-log kill is also known as 1×10^6 kill rate, which means reducing the number of live organisms by 6 orders of magnitude). Bulk material can be physically removed by cleanup methods that will leave a residuum that could be destroyed with a six-log kill. If one can not precisely identify the amount of contaminating material present at the start of a cleanup, then defining a specific level of remediation in terms of a log kill rate becomes difficult.

IDENTIFICATION OF THE AGENT

The biological agent used in an attack might become known as a result of a perpetrator's announcement, or it could be identified from physical recognition by trained personnel, from early presumptive test kit results, or from human symptoms. A rapid overt (announced) release will give rise to identification by physical and microbial analysis of substances obtained from obviously exposed surfaces. Health monitoring of exposed people is not likely to be necessary for identification. In the case of a covert release, environmental monitors, such as those that have been deployed in major cities as part of the BioWatch program or health monitoring of exposed people, might offer the first clues. The more likely scenario for detection of a covert release—based on past experience—would be the alarm raised by health professionals who would see an unusual disease such as anthrax or smallpox, or who might see several patients who are seriously and inexplicably ill.

Surveillance for increased incidence of common symptoms in targeted patient populations, known as syndromic surveillance, is one way to identify unusual clusters of disease that could result from an act of bioterrorism. Syndromic surveillance monitors the frequency of symptom complexes identified in patients before the confirmation of a medical diagnosis. The surveillance systems complement routine public health surveillance, and they commonly provide the advantage of near-real-time data entry, analysis, and reporting. The objective is to identify an attack as quickly as possible to allow for a rapid response and effective public health intervention. The alerts or warnings provided by the systems can initiate an epidemiological investigation to determine the source and extent of the exposure in the shortest possible time. Syndromic surveillance can be used to detect increases in influenza-like illness during periods of peak influenza A and B activity and of diarrhea and vomiting during periods of suspected norovirus and rotavirus transmission (Hefferman et al., 2004), but its ability to detect a bioterrorist attack has not yet been evaluated.

Substantial information can be obtained from microbial analysis of samples of serum, pus, scabs, and stools, as well as from environmental air and surface samples. A delay in identifying a decontaminating agent would afford the possibility of sustained agent viability and growth in mechanical spaces, crevices, and so on. Many types of sampling can be done, and different approaches are appropriate in different situations. The issues of cross contamination also must be

considered, including background suppression, cell desiccation, substance stabilization, viability after impaction, and other factors that can be affected by the choice of sampling approach. Sampling is discussed in detail in Chapter 8, which outlines presumptive identification made possible with the kits used by first responders and with other early microbial analysis methods, confirmatory identification methods, and the Laboratory Response Network.

The earlier contamination is detected the easier it will be to confine the contamination and limit the number of people exposed. Environmental monitoring and syndromic surveillance systems should be evaluated for the ability to provide information that can be used to detect and limit the spread of biothreat agents in a cost-effective manner.

Using Epidemiology to Identify the Agent

Efforts to identify a biological agent following an act of bioterrorism can be both difficult and time consuming. If there are no witnesses and no group claims responsibility for a deliberate release, nobody other than the perpetrator might be aware that an event has occurred, particularly if there are no real-time environmental monitoring systems at the site. In some instances, identification could only occur as a result of epidemiological monitoring or through medical diagnosis, as was the case at the AMI building in 2001. In such situations, it is difficult to determine whether the symptoms are the result of a natural outbreak or an intentional attack. That problem could be compounded by a lack of timely communication between epidemiologists and forensics experts.

Epidemiological Investigation Leading to Source Identification

A major bioterrorist attack could be unannounced or covert, and the source of the release might need to be identified through an extensive epidemiological investigation. Finding a *confirmed case* of the suspected disease is critical to many of those investigations. The definition may be clinical, with laboratory confirmation, or it could be done on the basis of laboratory evidence confirmed by one or two supportive laboratory tests. Suspected cases or clinically compatible cases linked to a confirmed environmental exposure, but without corroborative laboratory evidence of exposure or infection, may also be defined in an epidemiological investigation. Laboratory criteria for diagnosis must be defined as well. Follow-up includes enhanced case finding; retrospective and prospective surveillance systems; and environmental assessments and sampling of patients' homes, work sites, and travel destinations over the period preceding symptom onset and consistent with the incubation period of the suspected disease. Investigations can take weeks, during which time the released agent could be widely disseminated, in the case of spores, or transmitted, in the case of communicable diseases.

Epidemiological Factors Affecting Decontamination Efforts

Exposure reconstruction and risk characterization are important to epidemiological investigation and to decontamination. In the case of the letters tainted with *B. anthracis* spores, it was important to understand that exposure can be associated with the passage of powder-containing letters through the mail and to validate the model using empirical outcome data (CDC, 2001). Other research priorities include analysis of reaerosolization of settled spores and identification of risk for disease among secondarily exposed individuals; follow-up surveillance in those potentially exposed; the effects of long-term, low-level exposures; quantification of background contamination by potential agents in urban and rural environments; and identification of the occurrence of sporadic cases of zoonotic diseases that are considered possible threats. It also is necessary to decide how much sampling and decontamination will be done at satellite locations to which agents could have been transported.

EVALUATING THE STATE OF THE AGENT

Specific knowledge about the harmful biological agent used in an attack is important for emergency response, and it is essential for proper cleanup. Unlike the spores of *B. anthracis*, *Yersinia pestis* cells are sensitive to extremes in environmental conditions and therefore should not pose the same long-term hazard to the general population after a release (Inglesby et al., 2000). Naturally occurring *Y. pestis* is unlikely to remain viable for more than a few days after release, so its detection and identification can be troublesome. Recovery of viable organisms is unlikely unless samples are obtained and tested immediately after a release. Culturing the organism takes several days so PCR identification would be most timely, despite the fact that PCR cannot answer questions about viability. Like *Y. pestis*, variola major is sensitive to environmental conditions and in its natural form would not persist in droplets for long outside a human host.

For the case of biological agents, there also is the possibility of weaponization—engineering of the organism to improve its stability or other properties. In general, the weaponization begins with the growth of the agent (lag, log, and stationary phases each have unique properties mixed in with the culture media), then fermentation; centrifuging and separation; drying; milling for respirable particle size; additives to prevent aggregation and clumping, neutralize electrical charge, and increase survival in air; and microencapsulation for stability and viability. Each phase leaves physical and chemical clues that can help investigators to distinguish the agent substance from a normal background presence. Expertly prepared weapons are likely to be more resistant to natural attenuation and may be more resistant to decontamination.

Characteristics of Biological Agents That May Affect Hazard Assessment

The type of processing done before an agent is used as a weapon can alter how hazardous it is to humans and its persistence in the environment. This processing might be termed weaponization if it increases the ability of the agent to cause harm by making the agent more stable, more infectious, or better able to penetrate the human body. For agents that cause harm via inhalation, the size of the particles is crucial. Particle size also affects the ability of the agent to be aerosolized or reaerosolized.

Knowing the particle size of the pathogenic agent is critical in determining its potential for dispersal, reaerosolization, and infectivity—especially if the agent is released and spread as an aerosol. The particle size distribution depends on the agent (e.g., spore, vegetative cell, viron), the degree of weaponization sophistication (e.g., electrically neutralized, finely milled, encapsulated), and aerosol transport mechanism (e.g., dry cells, wet aerosol). A crudely weaponized agent is likely to have a large particle size distribution that varies from single particles of 0.2-2 μm to clumps of many particles or liquid droplets as large as 30 μm. Variola major virons can have complex shapes from 0.2-0.4 μm, *Y. pestis* cells are rod shaped and range from 0.5 × 1 μm to 1 × 2 μm, *B. anthacis* vegetative cells are rod shaped from 0.25 × 1 μm, and *B. anthracis* spores are spherical and 1-1.5 μm. There are many routes for hazardous insult by the threat agent ranging from contact with eyes or broken skin to inhalation into the respiratory tract. Infection is promoted by the growth of threat agent cells in local macrophages or by the proliferation of cells into the bloodstream. Most morbid infections stem from inhalation of aerosols though the nose or mouth. Large particle clumps or droplets (10-20 μm) can lodge in the mucosa of the nasal cavity or the pharynx, causing infection by local macrophages or gastrointestinal infection by ingestion. Particle clumps or droplets in the range 5-15 μm can lodge in the trachea. The most dangerous infections are caused by 0.1-10 μm particles lodged in the lungs, where they may be retained in the upper bronchiole region (5-10 μm particles) or in the lower alveolar region (0.1-5 μm particles).

The dynamics of particle size retention depend on the flow rate, mass impaction, diffusion, and gravitational settling which are, in turn, related to the activity of the person, tidal volume, and oral versus nasal inhalation. Several modeling efforts have helped to explain those dynamics. Calculations by Yu and Diu (1983) for spherical uncharged particles in the lung showed good agreement with experimental data. Yeh and Schum (1980) performed detailed in vitro measurements on lung molds created from human cadavers to validate deposition equations, again with spheres. Harvey and Hamby (2002) presented a model for deposition differences by age and sex. Generally the experiments show a retention rate of about 20-30% for 0.1-0.2 μm diameter spheres, which drops to about 10% for spheres in the 0.3-0.5 μm range and then rises to 90% or more at diameters 6 μm and greater. All of the models and data clearly reflect the partial clearance (exhala-

tion) of particles in the 0.3-3 μm range and the marked retention of larger diameter particles.

Retention of the actual organisms depends on other factors, such as the particle shape, the particle charge, and the hydrophilic or hydrophobic character. Goodlow and Leonard (1961) determined that the LD_{50} for *Francisella tularensis* aerosol in guinea pigs increased by nearly 4 orders of magnitude when the particle size of the organism was increased from 1 μm to 12 μm. Fothergill (1957) had published concordant work on the effects of particle size on the LD_{50} of 6 aerosolized pathogens in guinea pigs. More research is needed to explain the particle retention dynamics in the lung and the infectivity of real organisms in healthy people and also immunocompromised subjects.

One approach to characterizing an aerosol biological agent is called the agent-containing-particles per liter of air (ACPLA) method. That technology combines sample collection with a slit sampler, dichotomous sampler, or all-glass impingers with statistical analysis to determine numbers of a viable agent, such as *B. anthracis* spores, in a single particle. Studies that use liquid suspensions of *B. subtilis* spores have shown that not all spores in a suspension will be viable (Ho et al., 2001). It can be assumed that the same holds true for an aerosol of biological material. To test this hypothesis, ACPLA has been used in field trials for testing biological aerosol detectors. Particles in a bioaerosol may be of varying sizes and may contain a mixture of viable and nonviable particles. ACPLA determinations are important because a fundamental characteristic of a biological aerosol threat is that agent particles are linked to infectivity. Research that used *B. globigii* spores has shown ACPLA values of about 4.5 viable spores in a typical particle of 2.5-4 μm (Ho et al., 2001).

B. anthracis spores are about 1-1.5 μm—an appropriate size for deposition in the alveoli of the lung. The spores germinate in the macrophage to produce the anthrax toxin and capsule, which in turn initiate the cascade of events that leads to disease. Studies of anthrax outbreaks in employees in New England wool mills (Brachman et al., 1960) found that workers may have inhaled 600-2150 spore particles daily without becoming ill. Some 150-700 of the spore particles were less than 5 μm in diameter (Brachman et al., 1960). Dahlgren and colleagues (1960) reported that, even in the dirtiest parts of a goat hair processing plant, employees inhaled 600-1300 spores during the work day and that only 25% to 50% of those particles were smaller than 5 μm in diameter. Although daily exposure may have served as a mechanism through which the workers became immune, the spores also could have aggregated to form particles that were too large to reach deep into the alveoli of the lungs and thus never encountered macrophages. The data substantiate earlier reports of the correlation between larger particle size and increased LD_{50}.

Secondary aerosolization of biological agents is a subject of great debate. The agent's characteristics—its physical state (e.g., vegetative spore), particle size, shape, electrical charge, and hydrophobicity—are important. The agent

might also be transported with and by other kinds of cells (culture media, skin particles), in environmental dust and aerosols, and in weaponization platforms (silica, beads). Several recent investigations have used computational fluid dynamics models and calculations to predict the major effects of normal air circulation, wall turbulence, and particle diffusion (Fennelly et al., 2004; Scorpio et al., 2003). Those results, using spherical particles with aerodynamic particle diameters from 0.5-10 μm as a proxy for anthrax spores, predict exposures of as much as one LD_{50} per breath from reaerosolization of 1 gram of material lying dormant on a desk in a normal office. The reaerosolized lethal dose exposure has been predicted to present itself in as little as 10 minutes. In another investigation, data from air samples, dust, and swab samples from a contaminated U.S. Senate office building were used to estimate the reaerosolization of anthrax. Colony-forming units were measured for semi-quiescent and active periods, and the conclusion was that secondary aerosolization was probable and problematic. Recent laboratory experiments by the Defence Research Establishment, Suffield, Canada (Defence R&D Canada) using the simulant *B. globigii* (*B. atrophaeus*) measured the rate of accumulation of spores onto slit sample agar devices in several office settings.

EVALUATING THE STATE OF THE CONTAMINATED BUILDING

To completely assess risk, the amount of material initially used in an attack (the source term) must be identified to the extent possible. Initial loading and sample volume affect the types of sampling that can be done and the extent of cleanup required. The building's internal environment and its structure also are crucial. Humidity, air circulation, air exchange rate, mechanical complexity (HVAC system), architecture (stack effects), functional space (walls, floors, office material), and electrical complexity (lights, computers) all affect the rate of dissemination, viability, and lesion and reaerosolization. Those topics are discussed in Chapter 7.

FINDINGS AND RECOMMENDATIONS

Finding 6-1
Detailed characterization (including screening for known threat agents, genetically modified and emerging threat organisms) of a suspected biological pathogen is required for proper analysis and to inform decision making.

Recommendation 6-1
Research should be conducted to develop a characterization system that can inexpensively identify, or approximately characterize, all potential threat agents including genetically modified and emerging threat agents.

Finding 6-2
Identifying and characterizing the properties of an organism (or organisms), and

the amount and extent of its concentration at the time cleanup begins, are critical to making decisions about response options.

Recommendation 6-2
Characterizing the contaminating agent or agents should be done before selecting the approach for large-scale remediation. The remediation approach chosen should be one that can adequately destroy (or remove) the amount of agent present at the start of the procedure.

Finding 6-3
The earlier contamination is detected the easier it will be to restrict the area of contamination and the number of individuals who will be exposed. In the case of the 2001 anthrax letter mailings, the event first came to light through the observations of an astute physician. Different monitoring systems—environmental (e.g., Biowatch) and medical (e.g., syndromic surveillance) in nature—have since been put in place with the hope of obtaining the earliest possible indicator regarding the release of a biological agent.

Recommendation 6-3
Existing environmental monitoring systems and syndromic surveillance systems need to be evaluated for their abilities to provide information that can be used to detect and to limit the spread of biothreat agents in a cost effective manner. If those systems prove to be effective, they could be deployed in public facilities that may be likely targets for attacks.

REFERENCES

Brachman, P.S., S.A. Plotkin, F.H. Bumford, and M.M. Atchison. 1960. An epidemic of inhalation anthrax: the first in the twentieth century. II. Epidemiology. American Journal of Hygiene 72: 6-23.

CDC (U.S. Centers for Disease Control and Prevention). 2001. CDC Basic Laboratory Protocols for the Presumptive Identification of *Bacillus anthracis*. Atlanta, Georgia: CDC.

Dahlgren, C.M., L.M. Buchanan, H.M. Decker, S.W. Freed, C.R. Phillips, and P.S. Brachman. 1960. *Bacillus anthracis* aerosols in goat hair processing mills. American Journal of Hygiene 72: 24-31.

Fennelly, K.P., A.L. Davidow, S.L. Miller, N. Connell, and J.J. Ellner. 2004. Airborne infection with *Bacillus anthracis*—from mills to mail. Emerging Infectious Diseases 10: 996-1001.

Fothergill, I.D. 1957. Biological warfare and its defense. Public Health Reports 72(10): 865-871.

Goodlow, R.J., and F.A. Leonard. 1961. Viability and infectivity of microorganisms in experimental airborne infection. Bacteriology Reviews 25: 182-187.

Harvey, R.P., and D.M. Hamby. 2002. Age-specific uncertainty in particulate deposition for 1 mm AMAD particles using the ICRP 66 lung model. Health Physics 82:807-816.

Hefferman, R., F. Mostashari, D. Debjani, A. Karpati, M. Kulldorff, and D. Weiss. 2004. Syndromic surveillance in public health practice, New York City. Emerging Infectious Diseases 10(5): 858-864.

Ho, J., M. Spense, and J. Ogston. 2001. Characterizing biological aerosol in a chamber: an approach to estimation of viable organisms in a single biological particle. Aerobiologia 17: 301-312.

Inglesby, T.V., D.T. Dennis, D.A. Henderson, J.G. Bartlett, M.S. Ascher, E. Eitzen, A.D. Fine, A.M. Friedlander, J. Hauer, J.F. Koerner, M. Layton, J. McDade, M.T. Osterholm, T. O'Toole, G. Parker, T.M. Perl, P.K. Russell, M. Schoch-Spana, and K. Tonat. 2000. Plague as a biological weapon. Medical and public health management. Journal of American Medical Association 283: 2281-2290.

Scorpio, S.M., R.P. Roger, and A. Brandt. 2003. Simulation of bio agent release in a room or office space. Johns Hopkins APL Technical Digest 24(4): 376-280.

Yeh, H.-C., and G.M. Schum. 1980. Models of human lung airways and their application to inhaled particle deposition. Bulletin of Mathematical Biology 42:461-480.

Yu, C.P., and C.K. Diu. 1983. Total and regional deposition of inhaled aerosols in humans. Journal of Aerosol Science 14: 599-609.

7

Factors Influencing Exposure to Harmful Biological Agents in Indoor Environments

Exposure assessment, an important part of the decision-making process for the cleanup of a facility that is contaminated with biological weapons, is discussed throughout this report. In this chapter, the committee focuses on the ways that an agent can spread within a facility. Chapter 9 discusses ways to measure the amount of an agent and the extent of contamination. Chapter 9 also provides an overview of how sampling can be used to assess the effectiveness of decontamination.

An important step in the aftermath of the release of a harmful biological agent is to identify how extensively that agent might have spread within a facility. Many areas could be contaminated indirectly because of the way air circulates within the building and at its periphery. Biological agents, such as *Bacillus anthracis* spores, can behave as particulate solids or as droplets, thus allowing for extensive modeling. However, because those agents are living organisms, their characteristics can vary as can the effects they have within a population. An agent used in an attack could change over time as it is suspended into the air, settles onto surfaces, and is resuspended and its properties could alter under different environmental conditions. Some airborne agents (those without fast settling velocities) will be distributed and diluted by mechanical ventilation systems. Some will attach to surfaces, but later could be reaerosolized or resuspended.

Contaminants move in air in response to pressure gradients. Mechanical air-handling systems in many buildings use fans to create pressure gradients that move air through ducts, plenums, and exhaust shafts. The pressure gradients, the buoyancy of heated air, and wind flow around a structure allow for the infiltration or exfiltration of air, which provides conditioned air to the occupied areas or

removes odors, smoke, or airborne chemical compounds from bathrooms, kitchens, or laboratories. "Ventilation and air distribution are critical with respect to the issues [chemical, biological and radiological] agents entering buildings, their movement within buildings and their subsequent removal" (Persily, 2004).

Several factors determine exposure to biological and chemical agents released indoors, including the dynamic movement of agents throughout indoor environments. The concentrations will depend on the amount of agent generated, its chemical and physical properties, and how and where it is introduced. How an agent is consequently distributed depends on many factors of the built environment, including the air ventilation system and the characteristics of the interior surfaces.

Occupant behavior also can affect the distribution of pollutants. The actual exposure and dose will depend on gender, age, metabolic activity, clothing, behavior, and susceptibility, among other demographic and personal factors. The U.S. Environmental Protection Agency (EPA) published the *Exposures Factors Handbook* (1997), which provides values, distributions, and ranges for many physical and human factors that are applied to quantitative risk assessment. This section discusses a few of the factors that determine indoor concentration and exposures to potential biological and chemical agents. See http://www.epa.gov/ncea/pdfs/efh for more details.

EXPOSURE

Exposure to a contaminant is defined as an event or series of events that occur when there is contact at a boundary between a human and the environment with a contaminant of a specific concentration for an interval of time (NRC, 1999). Exposure is measured in units of concentration (ppm [parts per million], mass per volume) and time. Dose is the amount of a contaminant that is deposited or absorbed in the body over a unit of time. The dose of an airborne allergen or pathogen can be further defined as the amount deposited (delivered) to a specific sites such as the upper airways.

Epidemiology, controlled-exposure studies, and environmental assessments are used to determine the concentration of a contaminant in air, food, soil, dust, and water or on surfaces as a surrogate for exposure and for dose. It is important to distinguish surrogates from actual, measured exposure or doses because, in the context of biological and chemical assessments, measurements are not likely to be available. In some cases, only the presence of a substance in the air or on surfaces will be detected. Even with concentration data, the variability in actual inhalation or deposition exposures and variations in susceptibility within a heterogeneous population make estimates of risk inherently uncertain.

Consider the following example as another potential pathway leading to *B. anthracis* exposure: Assume that *B. anthracis* has been released in a small car-

peted room ($5 \times 3 \times 2.5$ m) that contains a table (1×2 m). Assume that 0.001 g of the material settles uniformly on horizontal surfaces. Wipe samples yield 35 ng cm^{-2} from the table and 3 ng cm^{-2} from the carpet. Uptake to a person who places a palm on those surfaces can be estimated by a simple formula:

$$U = (C)\ (A)\ (R).$$

C is the concentration on the surface, A is the area of skin in contact with the surface, and R is the removal efficiency of the skin.

To determine the actual concentration that is estimated from the wipe samples, it is necessary to know how much actually adheres to the material used to wipe surface. Depending on the methods used and the nature of the surfaces, the sticking coefficient typically is less than 1. In this example, the coefficient for the table is 0.5, for the carpet it is 0.1. So the equation is

$$U = (C_{wipe}/R_{wipe})\ (A)\ (R).$$

R_{wipe} is the collection (removal) efficiency of the wipe method for that contaminant and surface material.

Continuing with the example, the area of an adult palm is 150 cm^2 and the removal efficiency is estimated at 10%. The removal efficiency varies with the properties of the surface, the contaminant, and the skin and with pressure applied to the surface. For this example, the 10% might represent the area of the palm that actually touched the surface with 100% transfer. It is possible to estimate skin surface area for parts of the human body and to calculate values for soil or dust dermal uptake (EPA, 1997). The EPA *Exposure Factors Handbook* (1997) also discusses dermal transfer and gives an adherence rate of 0.2 mg cm^{-2} with a 95th percentile of 1.0 mg cm^{-2} for adults. Dermal loading can vary substantially for different activities and among people. Variations in the matrix of the contaminant, the amount of soiling on the skin, and the chemical and physical properties of the contaminant further complicate estimation of dermal loadings.

If only the finger tips touch the contaminated surface (15 cm^2), then about 0.001 milligrams (mg) of *B. anthracis* might be transferred. If there are 10^9 spores mg^{-1} of *B. anthracis*, perhaps as many as 1 million spores could be transferred to the hand. The transfer would be less from touching a flocked or fleeced surface. To render the example applicable to chemical contaminants, an additional factor for biological uptake through the skin would be included. Absorption rates (mg cm^{-2} h^{-1}) are available for several industrial chemicals in either the liquid or vapor phase.

More exposure can occur through the resuspension of spores. In our scenario, 1 mg of *B. anthracis* is uniformly distributed in a $5 \times 3 \times 2.5$ m room with 1 air change h^{-1}, and exposure after vigorous activity can be determined. Vigorous activity over an hour might result in a spore concentration of 0.3×10^{-14} g cm^{-3} as derived by:

$$C = (R \times \text{Surface Loading} \times \text{Area disturbed})/(\text{Volume} \times \text{air change})$$

$$(10^{-5}\ h^{-1})(70 \times 10^{-9} g/cm^2)(500\ cm \times 300\ cm)/(500\ cm \times 300 cm \times 250 cm)(1\ h^{-1}).$$

Consider a normal, nonexertion breathing volume of 5 L min^{-1} (10 breaths per minute × 0.5 liters per breath). Over an hour an adult would breathe in 300,000 cm^3 of air containing 0.003 spores cm^{-3} or about 1000 spores, if all the area were disturbed. Note that deposition in the lungs is not 100% for spores that are in the size range of 1-3 μm. From this simple example, one can see that the activity rates, the area disturbed, and the surface loadings are directly proportional to the concentrations, whereas the volume of the room and the air change rates are inversely related to concentration. Thus, increasing the flow of noncontaminated air, either by air cleaning or with fresh, will reduce concentrations.

SOURCES

There are many ways to release biological or chemical agents. Pathogens, spores, or chemicals can be sprayed from devices that create small droplets in a fog or mist or larger droplets. Such devices include pressure washers and pesticide application equipment. Hazardous agents might be contained in pressurized canisters that when punctured or pressed release their contents quickly. If the device is equipped with a valve or critical-flow orifice, the release can be prolonged. Exposure to weaponized *B. anthracis* from envelopes can also occur, as in the 2001 attacks. Secondary suspension of spores can occur as the spores are dispersed from surfaces by air currents or physical forces. The amount of resuspended material depends on a complex interaction of surface factors (tile, carpet), agent (static charges, surface coatings), and environmental conditions (humidity, air velocity).

Models for instantaneous or prolonged releases in a variety of scenarios and from many devices are available. Compliance with the regulatory requirements of the Comprehensive Environmental Reponse, Compensation and Liability Act (the Superfund law), the Clean Air Act Amendments, and the Federal Insecticide, Fungicide, and Rodenticide Act have led to the development of models that predict the near-field concentrations, surface deposition, and uptake of potentially hazardous materials. Those models are relevant to most scenarios that involve biological and chemical release, dispersion, and transport. However, the models are limited by the lack of attention to dissemination of infectious pathogens from humans or the activity of contaminants released indoors. Computational fluid dynamics (CFD) models are useful tools for predicting the general behavior of gases and aerosols released indoors.

Airborne infection risk depends on the emission rate of respirable or inspirable (but nonrespirable) particles of the pathogen, which could escape from

an envelope, be released by a mechanical device, or be transmitted in the expired breath of an infected person. Infection risk also depends on the rate of pathogen dispersion and removal from the indoor space, the location of susceptible persons relative to the emission points, and the pathogen's inhalation dose–response function. Other factors include breathing rate, particle deposition fraction in the respiratory tract, and the airborne or surface pathogen die-off rate attributable to environmental stressors. The pathogen emission rate must be estimated for the infectious host (number of cough h^{-1}), the pathogen concentration in respiratory fluid (number of pathogens mL^{-1}), and the respirable or inspirable particle volume per expiratory event (mL $cough^{-1}$). The fate and transport of emitted respiratory fluid particles could be approximately modeled with CFD but there are no models for predicting the viability of pathogens on surfaces or the potential for contact routes of infection. The Markov chain construct offers a different approach for predicting secondary infections for various combinations of ventilation system configuration and operation and occupancy. That construct seeks the conditional probability for new secondary infections based on the current state of infections and system configurations.

Models for common respiratory illnesses—influenza or colds in airplanes, schools, and nursing homes—could serve as a valuable tool for predicting the effects of exposure to infectious biological agents that could be released by terrorists. Those standard epidemiological models also could be used to assess the risks of emerging diseases transmitted through airborne viruses or bacteria. Examples of those models are available from the web site of the National Institute of General Medical Sciences (http://www.nigms.nih.gov/research/midas.html). The study of secondary cases of severe acute respiratory syndrome (SARS) in the Amoy Garden apartment complex in Hong Kong (Yu et al., 2004) illustrates the use of CFD modeling and explains building dynamics as they influenced the spread of the SARS virus both within the building containing the incident case and between adjacent buildings.

BUILDING DESIGN AND OPERATIONS

When people are exposed to a biological agent indoors, the exposure depends not only on the amount of agent released, which determines the strength of the source, but on how air moves through the building, the rate of exchange between indoor and outdoor air, and the rate at which the agent is removed from indoor air by air filters or surface deposition. The exchange of indoor with outdoor air is referred to as ventilation. The concentration of a contaminant inside a building or in an area within a building depends on the rate at which the contaminant is generated and then removed, whether by ventilation, air cleaning, or other processes such as chemical reactions or adsorption onto surfaces. The relationships among those factors can be studied with a mass balance model, which assumes that the air in a building is well mixed. Although that is not necessarily

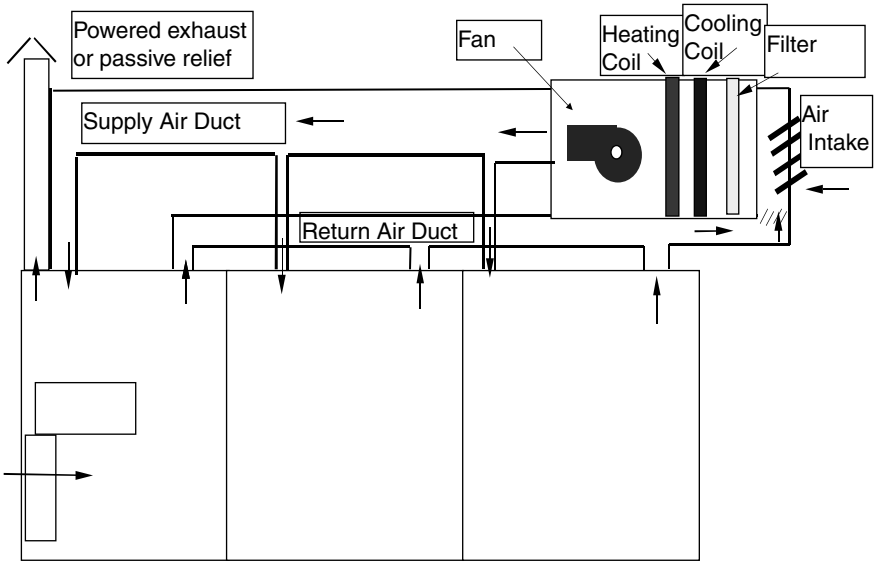


FIGURE 7-1 Typical air-handling unit. Arrows indicate airflow. SOURCE: Adapted from EPA, 1994.

the case, it provides a mechanism for analysis. Concentrations in a space increase with the amount generated, decrease with an increase in ventilation, and decrease in proportion to the amount of contaminant that is cleaned or removed from the air. Cleaning or removal might occur because of an active air-cleaning device, because of the naturally occurring deposition of particles onto surfaces, or because of a gradual loss of viability. Although this section of the report describes air-handling systems to illustrate air transport, transport by attachment to clothing for later transfer to other surfaces and possible resuspension is germane to assessing the full extent of biological contamination.

Relevant issues to consider in evaluating air flow and exchange include the type of ventilation in the building of concern. Buildings can be ventilated using natural or mechanical methods. Air can be supplied naturally through windows, louvers, and leak in building envelopes or mechanically through a heating, ventilating, and air conditioning (HVAC) system that usually includes fans, duct work, and a system for delivering air throughout a building (Figure 7-1).

In most houses, ventilation occurs by a natural exchange of indoor and outdoor air, at a rate of approximately 1 full air exchange every 2 hours. Commercial and public buildings generally have mechanical HVAC systems that move air through buildings to provide temperature control and ventilation at a rate of 2 or more per hour, although the amount of fresh air in the exchange can range from none at all to 100% depending on the system used. Minimum settings

are prescribed to meet ventilation codes. Variations in surfaces and their characteristics in buildings and microenvironments also should be considered. For example, most HVAC systems have air-cleaning filters that typically remove large particles but those are less efficient for particles smaller than 1 μm.

HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS

In modern public and commercial buildings, which often have sealed windows, some ventilation with outside air is required to provide a safe, functional, and comfortable environment for occupants. Mechanical ventilation systems are used to control contaminant concentrations in many indoor environments and to maintain a comfortable temperature and humidity. Such systems are often used in hospitals; larger office buildings; and in public gathering areas such as theaters, hotels, schools, restaurants, department stores, and airports. Mechanical systems control indoor temperature and humidity and dilute contaminants (Bearg, 2001). The systems also can be used to maintain necessary pressure differentials between areas, to extract and exhaust air from specific spaces, or to clean the air with filters, catalytic converters, and various sorbent beds. The efficiencies and costs for ventilation systems vary depending on specific requirements and settings (Liddament, 2001).

TRANSPORT AND FATE OF HARMFUL BIOLOGICAL AGENTS

In still air, a discharged agent—if it is larger than a few micrometers—might settle out quickly. If the particles are small enough to be suspended in the air, however, the agent might stay in a high concentration as it undergoes dispersion by diffusion. Bulk movement will be influenced by buoyancy (thermally driven movement). If the room air is not still, because the building has a mechanical air-handling system, or because people move about within the space, there will be some mixing that breaks up and disperses "pockets" of suspended agents throughout the air space. As the agent spreads and ages, its characteristics change as a result of coagulation, deactivation (by desiccation or oxidation), and surface deposition. This, along with ventilation and air cleaning, generally will lead to reduced concentrations.

The distribution of an agent within a building depends on the chemical and physical characteristics of spaces and on the characteristics of the agent. The characteristics of the HVAC system (open or ductwork) and the types of surfaces (paint, vinyl, tile, wood, masonry, carpet) will affect transport and fate. Encapsulated agents might be impervious to the environmental conditions found inside buildings. The viability of agents contained in liquid droplets will be influenced by building climate and surface conditions. As a consequence, the extent of the initial threat and the subsequent scope of required decontamination will differ from one building to another.

Although interactions in the air and at surfaces modify the concentration, concentrations within the original space will depend strongly on an exchange with less-contaminated air under most circumstances. Mechanically delivered air disperses constituents through mixing (turbulence) and dilutes them by supplying less-contaminated air and by forcing removal. Generally, mechanical mixing is more effective at reducing concentrations from a point source of contamination in a room than is diffusion alone in still air. Air exchange and surface removal processes act together to lower concentrations.

The concentration of an indoor contaminant in a building, or in a space within a building, depends on the rate at which the contaminant is generated and its rate of removal, whether by ventilation; air cleaning; or another process such as chemical reaction, adsorption, or deposition. Those relationships, defined as mass balance, imply that concentrations of a biological or chemical agent in a space will increase with the amount released, decrease by the amount of air exchanged in the space (presuming the ventilating air is cleaner), and decrease as a result of air cleaning and other removal or deactivation processes. The cleaning or removal might be accomplished by an active device or by inactive deposition of particles to surfaces; adsorption of gases onto materials; or disinfection as a result of exposure to ultraviolet light, desiccation, oxidation, or chemical reaction.

The committee was asked to consider actions that could be pursued in the aftermath of an act of bioterrorism. Understanding how biological and chemical agents are transported, dispersed, deposited, and removed is directly related to choosing a particular mode of action after such an event. The physics of those processes depends on agent characteristics (Riley et al., 2002).

DEPOSITION

Particles can settle onto horizontal and vertical fixed surfaces, clothing, and skin. Deposition to vertical surfaces is more relevant for particles that are smaller than 1 μm in diameter. Brownian diffusion is the predominant removal pathway, but the rate of movement through the boundary layer is also influenced by thermal and electrostatic forces. Mechanical mixing of room air can enhance deposition by reducing the depth of the boundary layer. Once small particles adhere to a surface, van der Waals forces are usually strong enough to prevent their resuspension by air currents. Particles can be dislodged from vertical surfaces by contact adhesion or by mechanical force. Deposition to horizontal surfaces depends both on Brownian motion diffusion and on gravitational settling. Larger particles settle faster.

Figure 7-2 shows the expected patterns for indoor particle deposition. Larger particles have higher deposition velocities. The figure shows that deposition of combustion products and photochemically produced particles smaller than 0.1 μm is independent of surface orientation. As gravitational forces dominate diffusion for larger particles, there is more deposition on floors than onto walls or

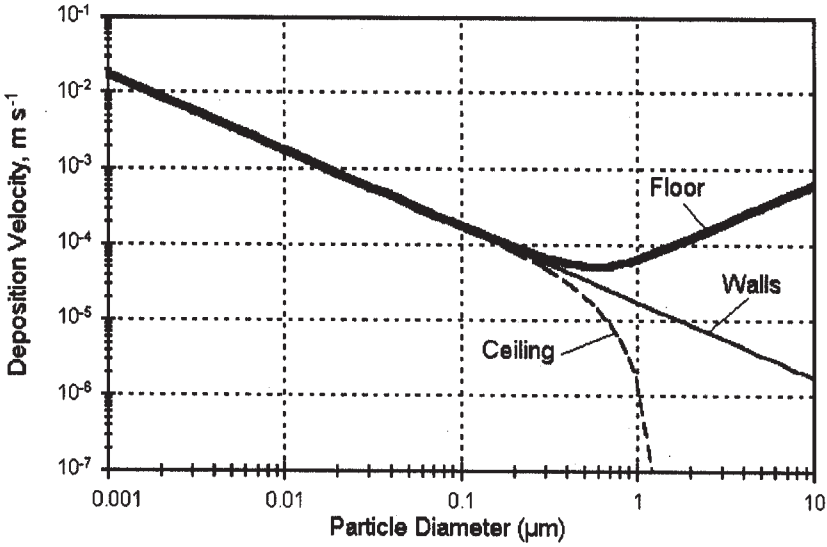


FIGURE 7-2 Idealized patterns of particle deposition indoors. SOURCE: EPA, 1997 (Adapted from Nazaroff and Cass, 1989).

ceilings. Deposition can be enhanced with mechanical mixing (caused, for example, by fans) and by electrostatically charging the particles. Electrostatic precipitators distribute charged ions that attach to airborne particles and increase their attraction to surfaces. The committee heard reports that *B. anthracis* spores were regularly detected in the wipe samples from computer screens at the National Broadcasting Company (NBC) office in New York City. Enhanced deposition occurs on TV and CRT displays and other charged surfaces.

RESUSPENSION

Resuspension and subsequent cleanup of biological and chemical agents deposited on surfaces are of primary concern for this report. The 2001 anthrax illnesses resulted from direct airborne exposures and from secondary exposure routes. Spores deposited on surfaces can be resuspended into the air and inhaled or can be reattached on other surfaces. *B. anthracis* spores were found in the air ducts and filters and on floors, desks, and other surfaces some distance from the initial point of release. They were found on surfaces in the apartment of an NBC employee who had been exposed at work. Those observations do not, in themselves, confirm that spores were resuspended, but the evidence is that resuspension of spores in surface resulted in the deposition of the spores on clothing.

Research on the resuspension of particles and radioactive material has been in progress for decades. A Los Alamos report by J.W. Healy (1971), *Surface*

Contamination: Decision Levels, examined radioactive particles resuspended from surfaces during various activities. The author estimates the resuspension rate of 5×10^{-3} h^{-1} for vigorous activities, such as cleaning, running, or active play on the floor. For moderate, slower foot traffic and occasional movement, the resuspension rate is estimated at 0.0001 h^{-1}. Observations taken over a full day, in a typical house where some portions of the day are more active than others, lead to a rate estimate of 3×10^{-4} to 5×10^{-4} h^{-1}. The Los Alamos study showed that material in dust on the floor can be transferred to clothing. Copper oxide particles were dispersed on the floor. Recovering mass from adhesive tape patches on various portions of a person's body showed average transfer of 22% h^{-1} from the floor. Frictional charge separation caused by walking on a surface can increase deposition to clothing.

More recently, several researchers (Ferro et al., 2004; Long et al., 2000; Rodes et al., 2001; Thatcher and Layton, 1995) have examined resuspension of particles, given different scenarios, in home and laboratory experiments. The activities studied included walking on hard and carpeted surfaces, vacuuming, and dusting. Thatcher and Layton (1995) measured indoor and outdoor particle concentrations in six size ranges for a detailed set of measurements in a single home where a family of four went about normal activities. The researchers used the mass balance method to estimate the amount resuspended indoors. Ferro and colleagues (2004) reported particulate matter (PM) concentrations generated for $PM_{2.5}$, PM_5, and $PM_{10,}$ (the subscripts indicate the maximum diameters of the particles in micrometers) for staged activities such as dancing, vacuuming, shaking blankets, walking on hard floors, and walking on rugs. According to Ferro (2001), "PM is defined as any substance larger than a molecule, either solid or liquid, which exists in atmosphere, and includes things such as soot, pollen, and sea spray. Next to second-hand cigarette smoke and cooking emissions, house dust resuspended by indoor human activity is the largest source of PM that we breath." Figure 7-3 shows how various activities affect PM_5 concentrations.

Rodes and colleagues (2001) reported particle measurements in different size classes for laboratory and home studies of subjects walking. Particles smaller than 1 μm were not readily dislodged from carpet fibers. As shown in Figure 7-4, more resuspension occurs with 3-15 μm particles.

Those studies also observed that resuspension rates are higher when the activities occur on carpet than they are for activities on bare floors. Higher dust loadings on carpets and possibly the mechanical forces of fiber recoil are likely explanations. In general, the experiments and modeling support the hypothesis that resuspension from activities involving carpet is 10 times higher than for activities on hard surfaces.

In the *Exposure Factors Handbook* (EPA, 1997), resuspension values derived from Thatcher and Layton (1995) are reproduced here (Table 7-1).

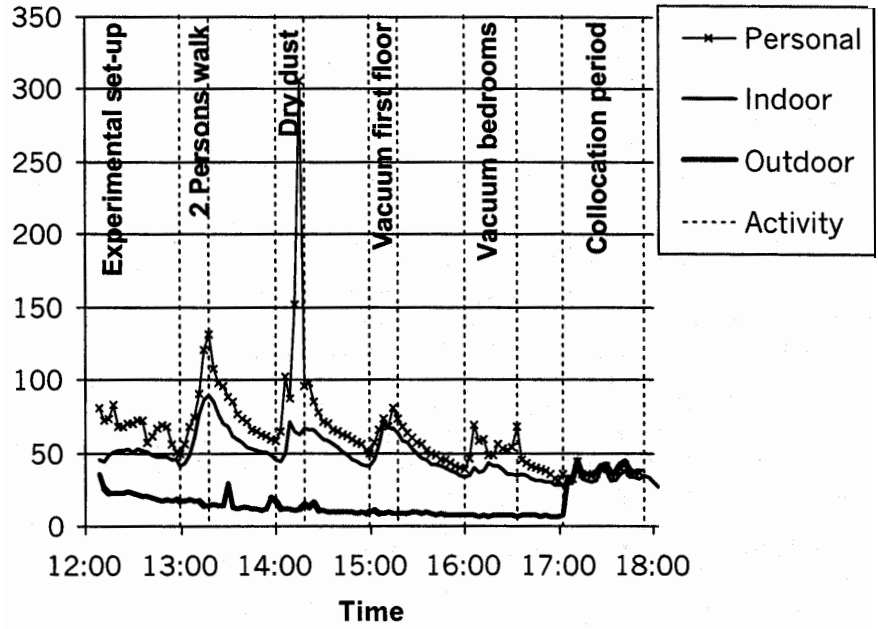


FIGURE 7-3 Personal, indoor, and outdoor PM_5 estimated mass concentration ($\mu g\ m^{-3}$) time series. SOURCE: Ferro et al., 2004.

PREPARING AND OPERATING BUILDINGS FOR A BIOTERRORISM ATTACK AND SUBSEQUENT OPERATION

Although HVAC systems are primarily designed for general ventilation, they can be considered part of the control strategy that might be adopted in the event of an act of bioterrorism. The proper use of HVAC systems for those cases will require a detailed understanding of the infectious or toxicological properties of biological agents, air distribution patterns, air-cleaning or extraction techniques, and the requirements for ongoing operation and maintenance (Ludwig, 2001). But even a properly designed and maintained HVAC system can actually exacerbate exposure by distributing the agent throughout a building during direct recirculation or transfer through poor pressure control. In most cases, it is unrealistic to plan for a risk reduction strategy that relies on reducing the concentration of the contaminant in the air supply. Although outside air dampers could be opened, supply fans generally are not large enough to provide the volume of air that would be effective. A typical HVAC system provides one complete air change every 8-15 minutes. An exhaust system also could be necessary to remove excess outside air from the building. Additional research by structural engineers

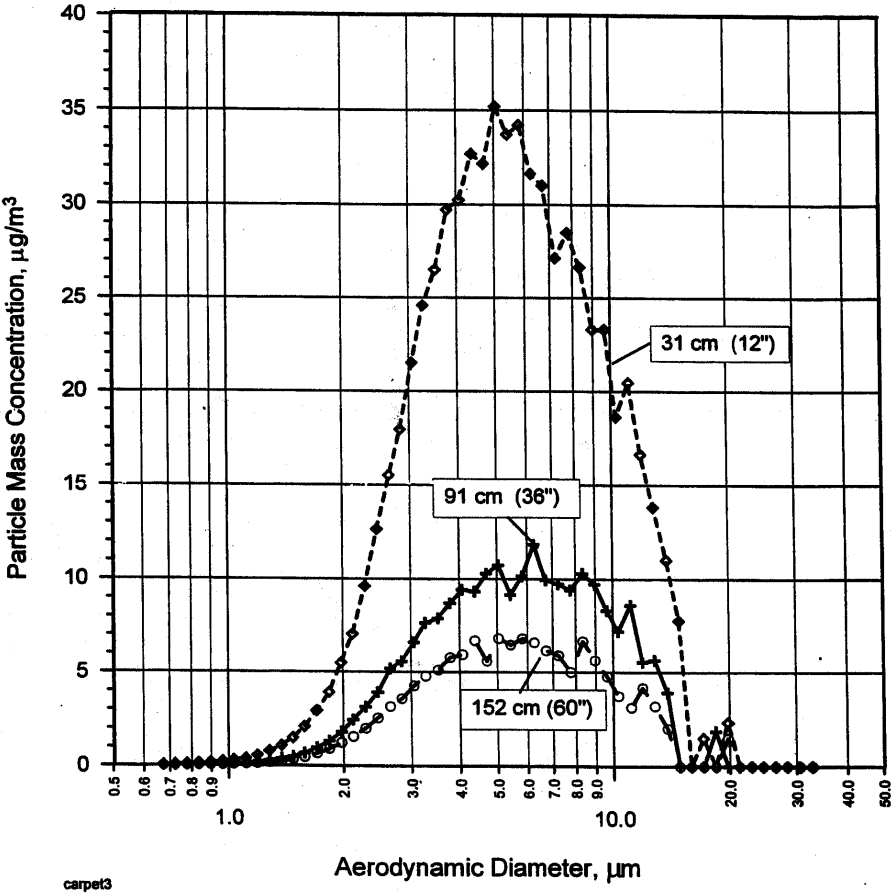


FIGURE 7-4 Computed house dust concentrations at three elevations above medium pile carpeting during walking events. SOURCE: Rodes et al., 1999.

and HVAC specialists might improve the knowledge base, allowing for greater certainty in decision making that is designed to minimize risk.

How a building facility manager might respond to a biological attack will depend on several factors. It might not be possible to determine, as it was for the Hart Senate Office Building and NBC, that the agent was distributed indoors. Attacks could involve external releases or introduction of the contaminant into garages, elevator shafts, loading docks, or air intakes. If a biological release occurs outdoors, the recommendation is to keep the air pressure of the building sufficiently positive to reduce infiltration. Exhaust fans could be shut off. Outside air dampers might be closed to the minimum setting so they continue to provide

TABLE 7-1 Particle Deposition and Resuspension During Normal Activities

Size Range, μm	Deposition Rate, h^{-1}	Resuspension Rate, h^{-1}
0.3-0.5	Not measured	9.9×10^{-7}
0.6-1	Not measured	4.4×10^{-7}
1-5	0.5	1.8×10^{-5}
5-10	1.4	8.3×10^{-5}
10-25	2.4	3.8×10^{-4}
>25	4.1	3.4×10^{-5}

SOURCE: Adapted from EPA, 1997, Table 17-26. Online: http://www.epa.gov/ncea/pdfs/efh/sect17.pdf.

sufficient intake to maintain pressure inside the building. It is important that filters in air-handling units remove particles that are in the size ranges of suspected weaponized agents, although filtration systems currently installed in most buildings are not likely to be effective against chemical, biological, or radiological agents.

The response to an internal release obviously would depend on the properties of the agent and location of the release, among other factors. If the specific location is determined promptly, specific rooms or areas might be isolated by depressurization in much the same way that hospitals prevent the spread of tuberculosis. Critical areas, such as loading docks, mail rooms, lobbies, restrooms, and garages, could be maintained at negative pressures to the adjacent areas.

Many buildings use zoning systems for air handling. Sections of a floor or a few floors might share a common air-handling unit. In those buildings, it should be possible to isolate floors or areas to create a containment for the contaminant.

Building ventilation strategies, in theory, might mitigate the consequences of an attack and limit the need for remediation. However, most buildings currently are not configured to implement such strategies in any emergency other than a fire. It will be some time before reliable and cost-effective sensors for biological contaminants or other toxic agents can be integrated into HVAC controls. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has made recommendations that can be implemented immediately (ASHRAE, 2003).

The basic tenets of the ASHRAE recommendations were reported by Persily (2004) and are summarized in Box 7-1.

FINDINGS AND RECOMMENDATIONS

Finding 7-1

Biological agents can spread beyond their point of initial release in air-handling systems, through the reaerosolization of contaminants from floors and other sur-

BOX 7-1
Recommended HVAC Systems Operations

- Recommission building to better understand zones and pressure relationships of critical areas. Correct deficiencies between design intent and actual operation.
- Document fan specifications, pressurization, and sequencing of operations for normal, smoke/fire control, and emergency shutdown.
- Document procedures for emergency shutdown of ventilation systems including exhaust systems. Train staff on all shifts and establish a chain of command. Trial runs of emergency shutdown may have unintended consequences creating business disruptions. HVAC controls might be restructured to permit easy access to quick shutoff switches.
- Secure mechanical rooms and outdoor air intakes. Relocation of air intakes may be necessary if access can not be restricted or monitored with surveillance cameras and/or alarms.

SOURCE: Additional information can be found on the Lawrence Berkeley National Laboratory website (www.lbl.gov).

faces by foot traffic or air currents, and by adhesion to people or their clothing. Those factors can result in widespread dispersal of biological contaminants within a building and into transportation and transit vehicles, homes, and other sites.

Recommendation 7-1
An extensive survey should be done to determine the extent to which biological contamination has spread. (Further guidance on surveying and sampling can be found in Chapter 9.)

Finding 7-2
Indoor air-handling systems can redistribute biological agents by carrying airborne contaminants throughout buildings and outdoors. However, if appropriate actions are taken, air-handling systems also can be used to confine contaminants and reduce the effects of contamination.

Recommendation 7-2
Building operators should act now to gain a thorough understanding of how air flow occurs in their buildings under normal operating conditions. They also should examine the potential adverse or beneficial effects of a shutdown on the spread of airborne contaminants so that appropriate actions could be taken to minimize the dispersal of contaminants if the release of a biological agent is identified.

Finding 7-3

Architects, construction engineers, ventilation engineers, facility operators, and other professionals involved with building design, construction, and operation have an inadequate understanding of how the built environment affects occupants.

Recommendation 7-3

The professions related to the building industry and facility management should be better educated on the nature of their vulnerability to weaponized agents so they will be prepared to respond to an act of bioterrorism. Professional societies (such as the Building Owners & Managers Association, and the International Facility Management Association), state and federal agencies, and academic institutions should fund and participate in efforts to increase understanding of those issues through education and training.

REFERENCES

ASHRAE. 2003. Risk Management Guidance for Health Safety and Environmental Security Under Extraordinary Incidents. Report of the Presidential Ad Hoc Committee for Building Health and Safety Under Extraordinary Incidents. Washington, DC: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.

Bearg, D.W. 2001. HVAC systems. Ch. 7 in Indoor Air Quality Handbook. J.D. Spengler, J.F. McCarthy, and J.M. Samet, eds. McGraw-Hill, Inc.

EPA (U.S. Environmental Protection Agency). 1994. Orientation to Indoor Air Quality. Washington, DC: Environmental Protection Agency.

EPA. 1997. Exposures Factors Handbook. Washington, DC: Office of Research and Development. EPA/600/P-95/002Fa.

Ferro, A.R. 2001. Breathing House Dust is Nothing to Sneeze At. [Online] Available at: http://www.stanford.edu/group/i-rite/statements/2001/ferro.hml (accessed on April 24, 2005).

Ferro, A.R., R.J. Kopperud, and L.M. Hildemann. 2004. Source strengths for indoor human activities that resuspend particulate matter. Environmental Science and Technology 38(6): 1759-1764.

Healy, J.W. 1971. Surface Contamination: Decision Levels. Los Alamos, New Mexico: Los Alamos Scientific Laboratory. LA-4558-MS.

Liddament, M.W. 2001. Occupant Impact on Ventilation. Air Infiltration and Ventilation Center. Technical Note 53.

Long, C., H. Suh, H.H. Koutrakis, and P. Koutrakis. 2000. Characterization of indoor particle sources using continuous mass and size monitors. Journal of Air and Waste Management Association 50: 1236-1250.

Ludwig, J.F. 2001. HVAC subsystems. Ch. 9 in Indoor Air Quality Handbook. J.D. Spengler, J.F. McCarthy, and J.M. Samet, eds. McGraw-Hill, Inc.

Nazaroff, W.W., and G.R. Cass. 1989. Mass-transport aspects of pollutant removal at indoor surfaces. Environment International 15: 567-584.

NRC (National Research Council). 1999. Research Priorities for Airborne Particulate Matter: II. Evaluating Research Progress and Updating the Portfolio. Washington, DC: National Academy Press.

Persily, A. 2004. Building ventilation and pressurization as a security tool. ASHRAE Journal 46(9): 18-24.

Riley, W.J., T.E. McKone, A.C. Lai, and W.W. Nazaroff. 2002. Indoor particulate matter of outdoor origin: importance of size-dependent removal mechanisms. Environmental Science Technology 36(2): 200-207.

Rodes, C.E., J.R. Newsome, R.W. Vanderpool, and J.D. Antley. 1999. Experimental Methodologies and Preliminary Mass Transfer Factor Data for Estimation of Dermal Exposures to Particles. Washington, DC: U.S. Environmental Protection Agency.

Rodes, C.E., P.A. Lawless, G.F. Evans, L.S. Sheldon, R.W. Williams, A.F. Vette, J.P. Creason, and D. Walsh. 2001. The relationships between personal PM exposures for elderly populations and indoor and outdoor concentrations for three retirement center scenarios. Journal of Exposure Analysis and Environmental Epidemiology 11(2): 103-115.

Thatcher, T.L., and D.W. Layton. 1995. Deposition, resuspension and penetration of particles within a residence. Atmosphere and Environment 29(13): 35-46.

Yu, I.T., Y. Li, T.W. Wong, W. Tam, A.T. Chan, J.H. Lee, D.Y. Leung, and T. Ho. 2004. Evidence of airborne transmission of the severe acute respiratory syndrome virus. New England Journal of Medicine 350(17): 1731-1739.

8

Analyzing Health Risks

ASSESSMENT OF RISKS POSED BY A BIOLOGICAL HAZARD

Dose–response analysis for microorganisms and for chemicals differs substantially in several ways. First, illness can result from the exposure to low numbers (up to tens or hundreds) of microorganisms. Illness attendant to exposure to chemical agents, even at low doses, involves exposure to substantially larger numbers of molecules (thousands or more). Also, even within a population exposed to small quantities of microorganisms, there can be large differences in the number of organisms to which individuals in a population are actually exposed (Figure 8-1). Hence, the intrinsic sampling variability—the fact that there can be significant differences in the actual numbers of organisms to which each person is exposed, even in a group exposed under the same average conditions—must be considered in the assessment of exposure and dose–response with microorganisms. Chemical risk assessment can ignore that phenomenon.

Figure 8-1 shows that at an average inhaled dose of 0.01 organism, there is a 1% probability of inhaling one organism (1 person in 100 exposed persons will inhale 1 organism). There is a somewhat smaller than 0.01% chance of inhaling 2 organisms. If the average inhaled dose is 3 organisms, there is about a 0.02% chance of inhaling 10 organisms. This shows that even if the average inhaled dose is low, there can still be a small fraction of the exposed population that will actually inhale an amount much larger.

The second difference is in the potential consequences of exposure to a single microorganism compared with exposure to one chemical particle. Plausible biological information indicates that one microorganism can cause harm in

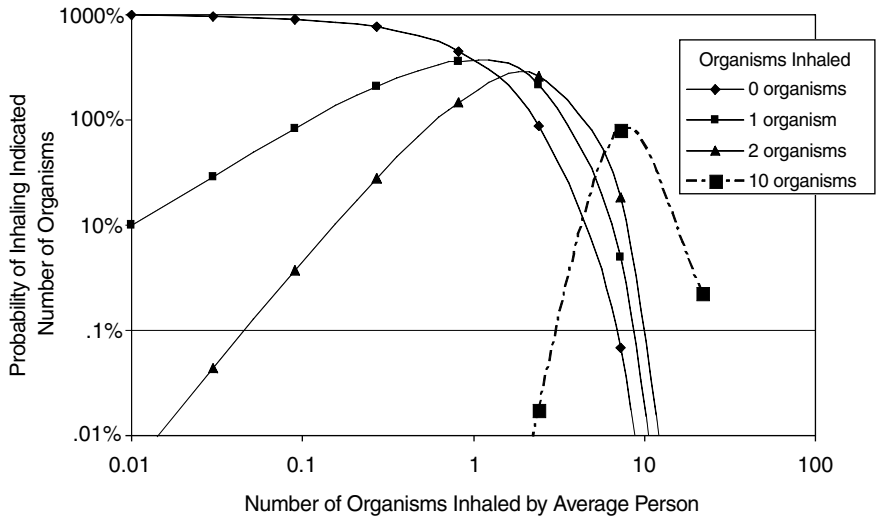


FIGURE 8-1 Probability of inhaling different numbers of organisms as a function of the average inhaled dose in a population (based on Poisson statistics).

the form of specific disease in specific subgroups of the human population (Rubin, 1987), whereas many particles of a chemical agent would be necessary to provoke an effect—depending on the chemical agent and the mode of action. In the case of microbial agents, an ingested, inhaled, or absorbed microorganism can multiply within the body of a susceptible human, to produce sufficient microorganisms in vivo that illness can result. However, the ability of the microorganisms to multiply does not imply that the exposure to a single organism will always produce illness, because the organism could be killed by defense processes—for example, the acidity of the gastrointestinal tract or the action of the immune system—before it can reproduce in sufficient numbers to cause an effect. That said, a single organism has the biological potential to produce an effect if a sufficient number of progeny are produced and survive. The ability of one organism to produce such an effect is strongly dependent on the susceptibility of the host, although susceptibility varies extensively in the human population, which consists of the young, the old, the healthy, and the immunocompromised.

The third difference is that the microbial exposure of one individual also can have a subsequent effect in the broader population (including persons who are not exposed directly). Some diseases are transmissible from person to person and can be spread even via asymptomatic individuals. Therefore, interpersonal contact can cause others to become ill. The degree of secondary spread depends on the organism's infectivity and its excretion pattern and on the behavior of infected persons.

A dose–response relationship describes the quantitative dependency of the proportion of the population that experiences an adverse effect (infection, illness, or death) caused by the average dose of microorganisms that the population receives (ingests, inhales, or contacts). Individual "points" on the relationship can be useful to describe the potency of the infectious agent; for example, the ID_{50} and LD_{50} denote the dose needed to infect or kill half of the population exposed, respectively. Those terms also are called the "median infectious dose" or "median lethal dose."

Unfortunately, summary tabulations of infectious agents often use the terms "infectious dose" or "lethal dose," without modifying adjectives. The result has been the misapprehension that doses below the ID_{50} and LD_{50} are without adverse effect. That interpretation is incorrect, and, for example, to ascertain the dose required to infect 1% of a population (which might be termed the ID_1), one would need to examine the dose–response relationship at low doses (and risks).

DOSE-RESPONSE: PRINCIPLES AND UNCERTAINTIES

Exposure to infectious organisms has been described with a dose–response construct at least since the 1950's. Wells (1955) described the process of inhalation infection as involving the statistics of inhalation of "quanta of infection," and he acknowledged an approximate exponential dose-response relationship by analogy with the most-probable-number bacterial assay. Riley and O' Grady (1961) elaborated on Wells's concept. They recognized that there may be various intrinsic and extrinsic modifiers of the infectivity of organisms.

All of those researchers' ideas about dose–response relationships have been used in industrial hygiene applications, inlcuding the analysis of tuberculosis risk (Nicas, 1996).

Although there are several dose-response models for infection or disease produced by pathogens, only one has been used with a Category A agent, and in that case the research involved animal hosts. Other dose-response models have not been published for other Category A agents, but there are data available that could be used to infer doses and responses for those agents (Table 8-1).

Since the early 1980s, a paradigm has emerged for describing risk attributable to exposure to microorganisms. Standard risk assessment techniques (dose–response assessment, exposure assessment) are used to estimate risk from pathogenic microorganisms (Haas, 1986; Haas et al., 1999a).

The two most successful dose-response models are the exponential model and the beta-Poisson model. Both models are derived from the following assumptions:

- A single organism surviving to colonize at a target site is sufficient to initiate the infectious disease process in some individuals.
- The probability that any ingested organism survives to colonization is independent among all organisms that are actually inhaled or ingested.

TABLE 8-1 List of Published Dose-Response Studies (or Data from which Dose–Response Could be Inferred) for Microbial Infection or Illness

Bacteria		
	Salmonella	(Fazil 1996; Holcombet al., 1999; Havelaar et al., 2000)
	Shigella	(Crockett et al., 1996)
	Enteropathogenic *E coli*	(Haas et al., 1999)
	E. coli O157:H7 (animals)	(Haas et al., 2000)
	Vibrio	(Haas et al., 1999)
	Campylobacter	(Medema 1996)
	Listeria (animals)	(Haas 1999)
	Bacillus anthracis (animals)	(Haas 2002)
	Francisella tularensis (animals)	(Oyston 2004)
Viruses		
	Rotavirus	(Haas et al., 1993; Gerba et al., 1996)
	ECHO	(Haas et al., 1999)
	Coxsackie	(Haas et al., 1999)
	Adenoviruses	(Haase et al., 1999)
	Ebola (animals)	(Johnson et al., 1995)
	Lassavirus (animals)	(Stephenson et al., 1984)
	Smallpox	(Wehrle et al., 1970)
Protozoans		
	Giardia (cysts)	(Rose et al., 1991)
	Cryptosporidium (oocysts)	(Haas et al., 1996; Messner et al., 2001; Teunis et al., 2002)

In the case of the exponential model, the survival probability is constant among all microorganisms. For the beta-Poisson model, the survival probabilities vary according to a beta probability distribution. The survival probability (in the case of the exponential) or the survival probability distribution (in the case of the beta-Poisson) accounts for all factors, including host immunity, that act as forces to reduce the ability of a retained organism to successfully colonize to the extent necessary to induce infection or disease. Both models predict that the risk at low doses is a linear function of dose. In several situations, outbreak data have been consistent with risks extrapolated from human volunteer trials (Crockett et al., 1996; Haas and Rose, 1994; Rose et al., 1991).

Dose–response modeling has been used extensively to posit the risk associated with ingestion (Cassin et al., 1998; Crockett et al., 1996; Gale et al., 1998; Haas et al., 1996; Medema et al., 1996) and dermal exposures (Gibson et al., 1999). Risks from inhalation have been modeled for bioaerosol emissions from sludge disposal operations (Dowd et al., 2000). A somewhat parallel model has been developed in the industrial hygiene literature in which an exponential model

is used to assess risk (Riley and O'Grady, 1961). Nicas (1996) modified that model to incorporate interhost variability, which effectively produces a set of models similar to the beta-Poisson model.

Animal Models

Although dose–response assessments have been developed for human subjects, such data are unlikely to be widely applicable. Some pathogens are so dangerous (for example, hepatitis A virus) that ethics rules prohibit their use in dose–response studies with human subjects. The effect of susceptibility on outcome would be difficult to ascertain from animal data alone—again because of ethical rules for the use of human subjects. Hence, the use of animal data for developing dose–response relationships and for ascertaining the influences of various modifying factors on outcome is clearly desirable. Yet there are no good animal models for some of the Category A organisms.

In the regulatory toxicology of chemical agents, animal model data are frequently relied on as a source of dose–response, or potency, information. The principles for the extrapolation to humans of results obtained in animal studies are well developed for chemical carcinogens (U.S. Interagency Staff Group on Carcinogenesis, 1986). However, in studying exposure to biological agents, scientists have less experience extrapolating from animal models to humans. A few studies have been done, but it is not necessarily straightforward to extrapolate from those examples to other agents.

Two studies have revealed promise for the use of animal dose–response data to develop human dose–response information (Haas et al., 1999b; 2000). The studies involve *Listeria monocytogenes* and *Escherichia coli* O157:H7. The disease rate during several human outbreaks examined (for those organisms) was consistent with the estimated exposure and with the use of the animal dose-response information without interspecies correction factors. The amount of information would be likely to expand as additional animal trials and validations are performed.

In the case of inhalation of *Bacillus anthracis* spores, primate data are consistent with an exponential dose–response relationship (Haas, 2002). Data appear to be available to perform dose–response analyses for other agents of concern, and such analyses should be done to develop dose–response relationships.

Relative Susceptibility of Different Subpopulations in Risk Analysis

As a matter of public policy, the guidelines for safe reoccupation of facilities contaminated with harmful biological agents should protect not only the general population but also sensitive or susceptible subpopulations. However, what constitutes *more susceptible* has not been rigorously defined. In 2000, a working group (Balbus et al., 2000) gave the following definition:

> Susceptibility is a capacity characterizable by a set of intrinsic and extrinsic factors that modify the impacts of a specific exposure upon risks/severity of outcomes in an individual or population.

By that definition, susceptible subpopulations could include the immunocompromised (including HIV-infected people and patients in treatment with immunosuppresive drugs), pregnant women, the elderly, and children (Gerba et al., 1996). In addition, it also could include persons with limited access to health care or with concomitant factors, such as diet, tobacco use, or use of illicit drugs, which could enhance their risk or susceptibility to infection.

However, there is no validated way to incorporate altered susceptibility into a risk assessment for infectious microorganisms. That will require the use of animal models to assess dose–response shifts associated with various modifiers to susceptibility. There could remain unresolvable uncertainties about which of the particular modifiers might be most appropriate, especially where good animal models are lacking for an agent.

"Thresholds" for Microbial Dose–Response Analysis

In assessing risks attributable to exposure to microorganisms, it has frequently been asserted that there exists a threshold (minimum infectious dose) below which there is no risk to a population. Such a concept is not consistent with the current understanding of microbial risk assessment, and the issue is addressed directly in this section. The no-risk concept originated from the fact that in trials (either animal or human), low doses of microorganisms often produced no adverse effects in exposed subjects.

Several terms should be precisely defined. A population exposed to microorganisms—for example, by inhaling contaminated air—is exposed to a dose for which an average can be calculated. For example, people who pass through a contaminated airport might be exposed to an average of 0.15 organisms (of a particular type) during their transit. However, microorganisms are individual particles at low number density[1] so that "average dose" means that some proportion of the population, perhaps most of it, would be exposed to zero organisms, and some proportion of the population would be exposed to 1, 2, or higher numbers of organisms.

The relationship between the average dose to a population and the proportion of that population that exhibits a particular adverse effect is called the dose–response relationship. The relationship between the actual number of organisms

[1]As an example, 100 microorganisms per m^3 of air is equivalent to 1.67×10^{-22} moles/m3, which is obtained by division by Avogadro's number. On a mass basis (using 10^{-12} g/organism) this would be 10^{-10} g/m^3 (or 100 pg/m^3). There are no environmental chemical contaminants that have yet caused concern at concentrations this low.

to which a subpopulation is exposed and the proportion of people in that exposed population to the actual number of people who experience the adverse effect is called the conditional dose-response relationship (Haas et al., 2002).

For in vitro quantification of organisms—such as by colony or plaque counting, most probable number, or $TCID_{50}$ (the dose that produces infection in 50% of the tissue culture samples exposed) methods—the underlying assumption for data interpretation is that a single microorganism is sufficient to generate a colony, plaque, or infected tube or lawn of cells. In other words, it is not necessary for more than one organism to be present for such infection to occur. However, it is recognized that the probability that any organism will actually initiate such an infection is not 100%. In specific terms, the conditional dose–response relationship is nonzero for an actual exposure to one organism in vitro. The same set of assumptions underlies the dose–response relationship used for assessing risk attributable to animal or human exposure to pathogens. Therefore, long-standing observations on microbial behavior have supported the use of population dose-response models without a threshold; that is, a dose below which no risk to a population exists (or a nonzero intercept on the dose scale).

All animal and human exposure data that have been subjected to dose-response analysis are consistent with models in which the dose intercept is zero and the value of the conditional dose–response relationship for one organism is nonzero. Hence, the concept of "minimum infectious dose" is consistent with the data, and there are no data for which a "threshold" is necessary (in the form of a nonzero intercept on the dose scale).

In animal and human trials, experiments are conducted with a small number of subjects. There are many reasons this is necessary, but one consequence is that it is harder to make robust conclusions about what would happen if larger numbers of subjects were exposed to a particular pathogen. For example, in a case where 10 nonhuman primates are studied it could appear that the pathogen has no effect (no positive reactions). However, if the same study were done using 100 nonhuman primates, several animals might exhibit an effect. That concept is shown in Figure 8-2. The probability of finding no affected subjects out of 10 as a function of the true proportion of positives in the population (the population risk) is shown. If the population risk were 0.1, there would still be a probability of 0.3 of finding zero positive subjects among 10. Hence, it would not be prudent to assert that a finding of no positives in a small sample would show that there is minimal risk in a large population. That concept explains how there could be situations in which it appears that there is a threshold dose below which there is no risk of exposure, when in fact there are not sufficient data available to conclusively establish that threshold.

Studies on the infection of laboratory animals with several infectious agents, as reviewed by Rubin (1987), provide strong experimental support for a nonthreshold methodology. The potential variations in agents of the same species and among potential human hosts (in immune status, for example) strongly sug-

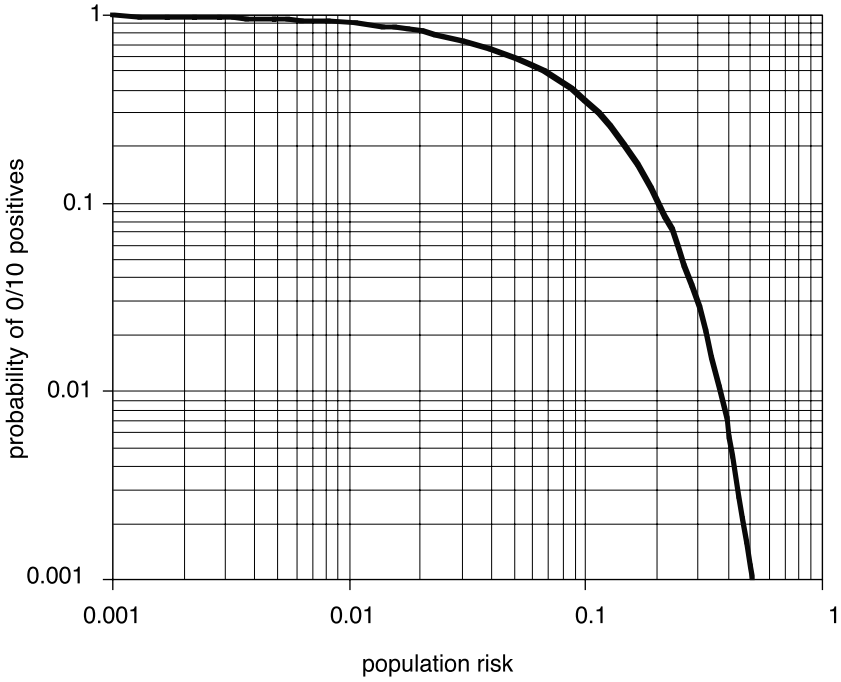


FIGURE 8-2 Relationship between the population risk and the probability of getting no positive subjects among 10 exposed (based on binomial probability).

gest that the limited information currently available should be interpreted cautiously. Although the nonthreshold model implies that there is no threshold below which an agent poses zero risk, it indicates that the probability of infection is extremely low.

In contrast, a threshold model implies a definitive threshold below which no infection would occur. So the nonthreshold model is a more cautious and more appropriate approach than is the threshold model in some circumstances. Therefore, the committee believes that prudent public health protection requires the continued application of nonthreshold approaches to the assessment of microbial dose response—that is, it is not possible to calculate a threshold for environmental contamination with *B. anthracis* spores (or other pathogens or toxins) below which there would be zero risk of disease. Microbial dose–response models can be divided into the categories of mechanistic and the empirical. Mechanistic models have been derived by considering the individual particle nature of microorganisms and the variability induced by small numbers that can be present in an individual exposure (for example, as noted in Figure 8-1).

The exponential and beta-Poisson models are examples of the class of mechanistic models that are derived by assuming that one organism, if it survives to colonize, is sufficient to initiate the infection and disease process. Alternative models can be derived on the basis that more than one organism is required to survive to colonize. For example, if the same assumptions as the exponential (identical and independent survival probabilities, random distribution of organisms) are used, except that the number of surviving organisms that successfully colonize must be at least $k_{\min}$ (>1), then the dose–response model becomes (Haas et al., 1999a)

$$p = \frac{1}{\Gamma(k_{\min})} \int_0^{d \bullet r} e^{-d \bullet r} z^{k_{\min}-1} dz$$

where d is the average dose, r is the individual survival probability, and p is the risk attributable to the exposure. This equation is also that of the gamma probability distribution. For all such "threshold" models (with $k_{\min}$>1), the slope of the dose-response relationship at the median (ID_{50}, LD_{50}) is steeper than it is in the non-threshold models. The available data on infectious organisms are inconsistent with dose–response relationships that have steeper slopes than the non-threshold models at the median, and therefore the concept of a threshold is not supported by available data.

Determination of Cleanup

The determination of the amount of cleanup required, and the processes used to achieve it, must consider both quantitative (risk assessment) and qualitative (stakeholder input) factors. Risk assessment can be used to inform the decision-making process in the specific context of cleanup of a facility after an act of bioterrorism.

The process can be described by a series of graphs. Figure 8-3 illustrates a relationship between the environmental concentration in a specific medium (such as surface and air) and the exposure of a specific population (such as workers, commuters, transient populations). Point A on Figure 8-3 represents the environmental concentration measured before decontamination (for example, organisms m^{-3} in air, or organisms m^{-2} on surfaces) on the x-axis, and the exposure (number of organisms) on the y-axis. The relationship must be developed by modeling exposure patterns and transport processes for potentially exposed individuals.

Point B of Figure 8-3 represents the environmental concentration and resulting exposure that can result from remediation by a specific decontamination strategy. The relationship can be nonlinear. By relating the resulting exposure after decontamination B to the dose–response relationship, the residual risk remaining after decontamination can be estimated. This is shown in Figure 8-4.

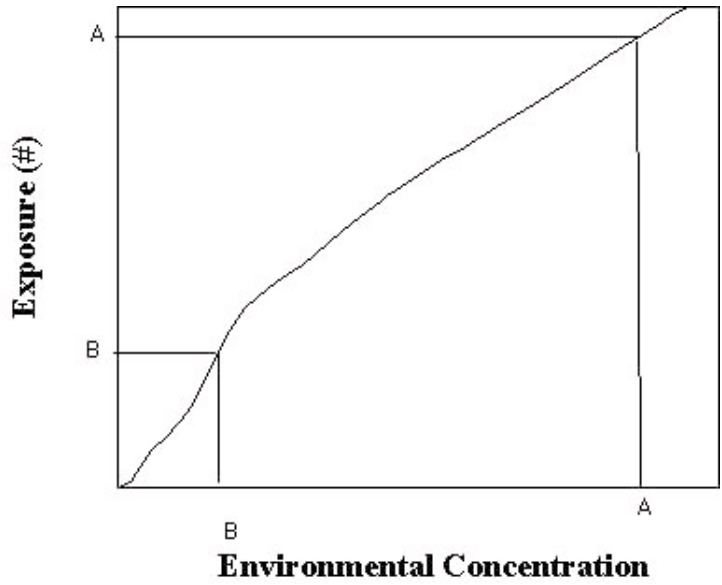


FIGURE 8-3 Relationship between environmental concentration versus exposure.

Therefore, the reduction in the environmental concentration (from A to B in Figure 8-3) results in a reduction in risk from A to B in Figure 8-4.

Figures 8-3 and 8-4 can be ascertained only with some level of uncertainty and variability. A partial list of sources of uncertainty and variability is given in Table 8-2. The uncertainties and variability would lead to the development of risk assessments in which confidence limits (or distributions) for each of the inputs are used to derive a confidence limit (or distribution) for the risk and/or the use of an empirical "safety factor."

Figures 8-3 and 8-4 can be used by a risk manager to assess the risk attributable to reducing environmental concentration to a target amount (going from Figure 8-3 to Figure 8-4). Alternatively, if a target risk is specified, the resulting dose can be computed via Figure 8-4 and the resulting environmental concentration can be computed from Figure 8-3. An illustration of the latter procedure is given in Box 8-1.

Close examination shows that there are several numerical inputs in Box 8-1: dose–response parameter, breathing rate, duration, transference ratio. Each has a specific uncertainty and variability, so the final estimate of surface and air concentrations corresponding to the risk level (or, conversely, the risk resulting from a given set of surface and air concentrations) itself has a certain confidence distribution.

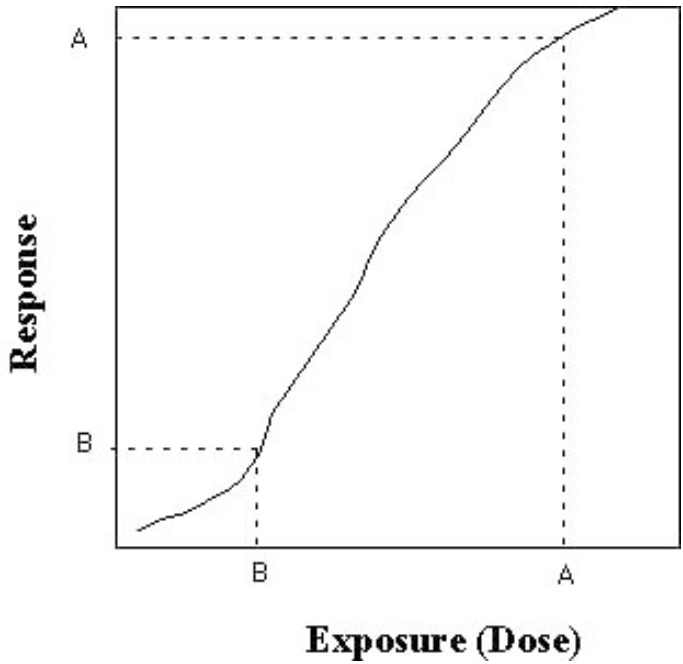


FIGURE 8-4 Schematic exposure (dose) response.

Appendix E presents a detailed probabilistic application of risk analysis in which the propagation of uncertainty and variability is set forth. For the American Media, Inc., building in Boca Raton, Florida, the example also shows that the computation of risk from inhalation of *B. anthracis* provides an estimate of disease impact that is consistent with the observed number of cases. The example in Appendix E shows that risk assessment and epidemiology are complementary pursuits, and that the results of epidemiological investigation can (with information on exposure) help support the computations of a risk assessment.

FINDINGS AND RECOMMENDATIONS

Finding 8-1

The concept of a "threshold" below which no risk to a population exists for a microbial dose response is not supported by currently available data. Nonthreshold dose–response models present a more cautious approach that has been found appropriate for describing human response to a diversity of infectious agents via ingestion, inhalation, and other routes of exposure. Dose–response data for most of the pathogens of concern (biological agents) are incomplete or have not been critically analyzed in the open literature.

TABLE 8-2 Some of the Uncertain and Variable Factors in Risk Assessment

	Uncertainty	Variability
Concentration/exposure relationship	• Physical factors leading to transport, decay, and/or removal of organisms • Biotic factors influencing microbial survival, fate, and transport	• Personal behaviors such as activity level • Protective equipment • Fluctuations in transport (e.g., air currents)
Exposure/response relationship	• Extrapolation from animal to human studies • Multiple studies	• Intra-individual susceptibility ✻ Age-infants have less well-developed immune systems and the elderly are frequently less able to respond effectively to immunological challenges ✻ Immune status—certain diseases such as HIV/AIDS attack the immune system leaving individuals highly susceptible to other infections. Patients undergoing cancer therapy have temporarily weakened immune system ✻ Concurrent illnesses may have a similar effect in challenging immune response to the most recent insult ✻ Behavioral factors—smoking and excessive drinking—may increase individual's susceptibility to infection and disease • Virulence and pathogenicity alterations • Preexisting prophylaxis and vaccination

an

BOX 8-1

The risk resulting from contamination of a room with spores of *Bacillus anthracis* must be assessed. The concentration in the air comes from spores that are resuspended from a surface. Surface concentrations also are measured. The following is assumed:

- A dose–response relationship for anthrax inhalation derived from the data of Druett and colleagues (`953). This is an exponential equation of the following form (Haas 2002)

$$p = 1 - \exp\left(-7.16 \bullet 10^{-6} d\right)$$

- where p is the risk and d is the dose (per exposure)
- The target risk to be achieved after decontamination is 10^{-7} (per exposure).
- Ten exposure is considered to have occurred when an individual is present in the area for 1 hour and breathing at a rate of 18 m^3/day—i.e., a total of 0.75 m^3 is inhaled in that hour. For the example, it is assumed that this represents the period during which an exposed individual is present, and it could differ for different situations (8 hours per day for a worker who stays in the same place; perhaps 10 minutes for a transient visitor).
- The "transference" of spores from surfaces to the air can be modeled by an equilibrium partitioning in which the ratio is (1 spore/m^3)/(10 spores/m^2), or 0.1 m^{-1}.
- First, from the dose–response relationship, given the risk, the dose can be computed as follows:

$$10^{-7} = 1 - \exp\left(-7.16 \bullet 10^{-6} d\right)$$

$$d = 0.014$$

- Because an exposure is to 0.75 m^3 of air, the resulting estimate of an environmental concentration in the air is 0.014/0.75 = 0.019 spores/m^3 of air (19 spores/1000 m^3).
- From the transference ratio, the surface concentration is determined to be 19×0.1 or 1.9 spores/1000 m^2 of surface.
- From that estimate, the degree of treatment needed to reduce the initial loading, corresponding to any particular residual risk, can be assessed, and the nature of a sampling program can be designed to ensure that the necessary degree of reduction is achieved.

Recommendation 8-1

Available dose–response data for pathogens of concern should be analyzed by nonthreshold dose–response models.

Finding 8-2

Because minimal publicly available data exist on which to base human dose–response relationships for the critical pathogens, animal data must be used. How-

ever, our understanding of interspecies extrapolation of dose–response relationships for infectious agents from animals to humans is low.

Recommendation 8-2
Targeted research to help inform decision making on extrapolation of dose–response data between species for the pathogens of concern should be conducted. That research might use several species of organisms or use animal and human tissues to reach conclusions that are relevant for human exposures. With the increasing difficulty of performing primate studies, it will become more important to develop in vitro techniques that can be used to develop dose-response information.

REFERENCES

Balbus, J., R. Parkin, and M. Embrey. 2000. Susceptibility in microbial risk assessment: definitions and research needs. Environmental Health Perspectives 108(9): 901-905.

Cassin, M.H., A.M. Lammerding, E.C.D. Todd, W. Ross, and R.S. McColl. 1998. Quantitative risk assessment for *Escherichia coli* O157:H7 in ground beef hamburgers. International Journal of Food Microbiology 41: 21-44.

Crockett, C.S., C.N. Haas, A. Fazil, J.B. Rose, and C.P. Gerba. 1996. Prevalence of shigellosis in the U.S.: consistency with dose-response information. International Journal of Food Microbiology 30(1-2): 87-100.

Dowd, S.E., C.P. Gerba, I.L. Pepper, and S.D. Pillai. 2000. Airborne pathogens in association with biosolids: mathematical modeling and risk assessment. Journal of Environmental Quality 29: 343-348.

Druett, H.A., D.W. Henderson, L. Packman, and S. Peacock. 1953. Studies on respiratory infection. I. The influence of particle size on respiratory infection with anthrax spores. Journal of Hygiene (London) 51(3): 359-371.

Fazil, A.M. 1996. A Quantitative Risk Assessment Model for *Salmonella*. Philadelphia, Pennsylvania: Environmental Studies Institute, Drexel University.

Gale, P., C. Young, and D. Oakes. 1998. A review: development of a risk assessment for BSE in the aquatic environment. Journal of Applied Microbiology 84(4): 467-477.

Gerba, C.P., J.B. Rose, C.N. Haas, and K.D. Crabtree. 1996. Waterborne rotavirus: a risk assessment. Water Research 30(12): 2929-2940.

Gibson, L.L., J.B. Rose, and C.N. Haas. 1999. Use of quantitative microbial risk assessment for evaluation of the benefits of laundry sanitation. American Journal of Infection Control 27(6): S34-39.

Haas, C.N. 1986. Wastewater disinfection and infectious disease risks. CRC Critical Reviews in Environmental Control 17(1): 1-20.

Haas, C.N. 2002. On the risk of mortality to primates exposed to anthrax spores. Risk Analysis 22(2): 189-193.

Haas, C.N., and J.B. Rose. 1994. Reconciliation of Microbial Risk Models and Outbreak Epidemiology: The Case of the Milwaukee Outbreak. Annual Conference—American Water Works Association, New York.

Haas, C.N., J.B. Rose, C.P. Gerba, and S. Regli. 1993. Risk assessment of virus in drinking water. Risk Analysis 13(5): 545-552.

Haas, C.N., C.S. Crockett, J.B. Rose, C.P. Gerba, and A. Fazil. 1996. Infectivity of *Cryptosporidium parvum* oocysts. Journal of the American Water Works Association 88(9): 131-136.

Haas, C.N., J.B. Rose, and C.P. Gerba. 1999a. Quantitative Microbial Risk Assessment. New York: John Wiley.

Haas, C.N., A. Thayyar-Madabusi, J.B. Rose, and C.P. Gerba. 1999b. Development and validation of dose-response relationship for *Listeria monocytogenes*. Quantitative Microbiology 1(1): 89-102.

Haas, C.N., A. Thayyar-Madabusi, J.B. Rose, and C.P. Gerba. 2000. Development of a dose-response relationship for *Escherichia coli* O157:H7. International Journal of Food Microbiology 56(2-3): 153-159.

Havelaar, A.H., J. Garssen, et al. (2000). Dose Response Relationships for Gastrointestinal Pathogens in an Animal Model. Bilthoven, NL, RIVM.

Holcomb, D.L., M.A. Smith, G.O. Ware, Y.C. Hung, R.E. Brackett, and M.P. Doyle. 1999. Comparison of six dose-response models for use with food-borne pathogens. Risk Analysis 19(6): 1091-1100.

Johnson, E., N. Jaax, J. White, and P. Jahrling. 1995. Lethal experimental infections of rhesus monkeys by aerosolized ebola virus. International Journal of Experimental Pathology 76: 227-236.

Medema, G.J., P.F.M. Teunis, A.H. Havelaar, and C.N. Haas. 1996. Assessment of the dose-response relationship of *Campylobacter jejuni*. International Journal of Food Microbiology 30(1-2): 101-112.

Messner, M.J., C.L. Chappell, and P.C. Okhuysen. 2001. Risk assessment for *Cryptosporidium*: a hierarchical Bayesian analysis of human dose-response data. Water Research 35(16): 3934-3940.

Nicas, M. 1996. An analytical framework for relating dose, risk and incidence: an application to occupational tuberculosis infection. Risk Analysis 16(4): 527-538.

Oyston, P.C.F., A. Sjostad, and R.W. Titball. 2004. Tularemia: bioterrorism defense renews interest in *Franciscella tularensis*. Nature Reviews Microbiology 2: 967-978.

Riley, R.L., and F. O'Grady. 1961. Airborne Infection: Transmission and Control. New York: Macmillan.

Rose, J.B., C.N. Haas, and S. Regli. 1991. Risk assessment and the control of waterborne giardiasis. American Journal of Public Health 81: 709-713.

Rubin, L.G. 1987. Bacterial colonization and infection resulting from multiplication of a single organism. Reviews of Infectious Diseases 9(1): 488-493.

Stephenson, E.H., E.W. Larson, and J.W. Dominik. 1984. Effect of environmental factors on aerosol-induced Lassa virus infection. Journal of Medical Virology 14: 295-303.

Teunis, P.F.M., C.L. Chappell, and P.C. Okhuysen. 2002. *Cryptosporidium* dose response studies: variation between hosts. Risk Analysis 22(3): 475-485.

U.S. Interagency Staff Group on Carcinogenesis. 1986. Chemical carcinogens: a review of the science and its associated principles. Environmental Health Perspectives 67: 201-282.

Wells, W.F. 1955. Airborne Contagion and Air Hygiene. Cambridge, MA: Harvard University Press.

Wherle, P.F., J.J. Posch, K.H. Richter, and D.A. Henderson. 1970. An airborne outbreak of smallpox in a German hospital and its significance with respect to other recent outbreaks. Bulletin World Health Organization 43: 2230-2251.

9

Sampling Strategies and Technologies

SAMPLING AND IDENTIFICATION

Substances that are believed to be biological weapons agents can be extracted for analysis from samples collected with surface wipes, vacuum filters, air filters, and liquid reservoirs and agar plates with air-impacted material, or from bulk solid or liquid materials that have been exposed. First responders to an incident are likely to use portable collection, detection, and identification devices or kits for the rapid characterization of those agents. Generally, the samples are hydrated and introduced to the detector kits to obtain a colorimetric or electronic display for rapid identification. The committee considered post-attack sampling as a source of data that would inform the assessment of the extent and degree of contamination, identify morphological changes in the substance, and monitor the effectiveness of decontamination. All of those phases of identification require confirmatory data and analysis. None should be limited to rapid identification systems.

Confirmatory procedures can be done by mobile on site laboratories or by the Centers for Disease Control and Prevention's (CDC) Laboratory Response Network (LRN). It is important to consider the goal of the sampling, and to match it to the proper procedure. For example, polymerase chain reaction (PCR) sampling can provide information about whether DNA from an agent of concern is present, but it can not provide information on whether that agent is alive or growing in a facility.

In 1999, the LRN was established to respond to acts of biological and chemical terrorism. The LRN system has expanded significantly since its inception, and

it now consists of 120 state and local public health, veterinary, and military laboratories and international laboratories of those types, that normally perform public health analyses. Collectively, the facilities are equipped to respond quickly to acts of biological terrorism, emerging infectious disease, and other public health threats (CDC, 2004). The LRN national network of laboratories includes:

Federal—These include laboratories at CDC, the U.S. Department of Agriculture, the Food and Drug Administration, and other facilities run by federal agencies.

State and local public health—These are laboratories run by state and local departments of health. In addition to being able to test for Category A biological agents, a few LRN public health laboratories are able to measure human exposure to toxic chemicals through tests on clinical specimens.

Military—Laboratories operated by the Department of Defense, including the U.S. Army Medical Research Institute for Infectious Diseases (USAMRIID) at Fort Detrick, Maryland.

Some laboratories are designated as national, reference, or sentinel, according to the tests they perform and how they handle infectious agents to protect workers and the public.

National laboratories include the CDC and USAMRIID. They have unique resources to handle highly infectious agents and the ability to identify specific agent strains.

Reference laboratories , sometimes referred to as "confirmatory reference," can perform tests to detect and confirm the presence of a threat agent. Reference laboratories are intended to provide local authorities with effective laboratory support on a timely and responsive basis, so that they do not need to rely on CDC support for all cases.

Sentinel laboratories represent the thousands of hospital-based laboratories that are on the front lines. Sentinel laboratories have direct contact with patients. In an unannounced or covert terrorist attack, patients provide specimens during routine patient care. Sentinel laboratories could be the first facility to spot a suspicious specimen. A sentinel laboratory's responsibility is to refer a suspicious sample to the right reference laboratory.

Bacillus anthracis has been identified as an agent used by bioterrorists. Its spores cause disease readily, and it is resistant to most adverse environmental conditions, such as extremes in temperature, sunlight, and drying (Bohm, 1990).

B. anthracis spores can live for decades without loss of viability (Turnbull, 1990). But its unique colony morphology and relatively fast growth in culture make its identification straightforward. In contrast, plague bacterium (*Yersinia pestis*) and smallpox virions are more fragile and susceptible to damage. PCR testing can be used definitively for positive identification of the agents of concern in this report. However, PCR testing does not differentiate live and dead agents; it merely provides DNA evidence that an agent is present. Consequently, in the case in which viability is important and the ability to grow samples in culture becomes important, the choice of sampling and preservation methods is crucial.

Specific sampling protocols should follow *a General Sampling Plan*, described later, which is developed by stakeholders, laboratories, and representations of public health and law enforcement agencies. The plan should allow for several factors that can complicate sampling for identification:

- *Suitability* of the antibody, DNA, or RNA probes against a variety of agents and strains in terms of their specificity, microbial stability, and handling requirements (refrigeration).
- *Background false alarms* caused, for example, by more than 200 microoganisms that have been collected in single-office environments, and many of them could be mistaken for biothreat agents because of preliminary information that could suggest that *B. anthracis* is present when the agent is in fact *B. subtilis* or *B. cereus.*
- *Background suppressions* caused by other substances (oils, cleaning solutions) and high background biological loads can compromise the functionality of samplers and sensors.
- *Growth and morphological changes* over time of the agent in high humidity, closed areas, crevices, and mechanical spaces.
- *Redistribution of the agent* by normal air circulation and turbulence and by the movement of personnel and equipment after an attack.
- *Uncertainties* about persistence, cost, time, safety, environmental, and treaty concerns. It is difficult to perform exhaustive, conclusive tests in the presence of factors that affect the viability of biological threats. There is great uncertainty about the way different substances react to humidity, ultraviolet light, and temperature. For example, it is well known that the smallpox virus is not as susceptible to high humidity as are some other virus species. The 1969 outbreak of smallpox in the hospital in Meschede, Germany (Wehrle et al., 1970) demonstrated that, even though the index patient was isolated, 19 other patients and medical care personnel were infected over a 1 month period, and 4 died. The spread of the virus was attributed to the aerodynamic stack effect of the stairway between three floors and the leakage from an open window. One patient died who had been located in a room two floors above the index case. Fever and rash occurred as long as 33 days after the end of the presumed infectious period of the index case.

GENERAL SAMPLING PLAN FOR QUANTIFYING THE EXTENT OF CLEANUP

Sampling after an attack and after the initial identification is intended to provide data to define the extent of contamination and the risk for responders and building occupants. A general sampling plan for a contaminated facility can provide a roadmap for verifying the results of decontamination. Cleanliness criteria can be developed by a team that includes facility stakeholders; medical, public health, and environmental experts; decontamination technologists; laboratory analysts; and worker safety representatives. According to the building function and the acceptable risk derived from the team's consensus agreement, the sampling plan should be reviewed by representatives of local, state, and federal agencies and by laboratory analysts; facility managers; structural engineers; and heating, ventilation, and air-conditioning (HVAC) engineers. The plan of action and milestones for sampling depend on the biological threats and contaminants present. Spores are hardier and more persistent than are vegetative cells, so spore sampling and retrieval conceivably could be more direct than would be possible if more fragile and dynamic vegetative material were the cause for remediation. Virions are more difficult to obtain and preserve for characterization because of their mechanical fragility and sensitivity to temperature and pH.

The systems engineering discipline can help define the sampling subsystems, interfaces, and tradeoff analyses in the general sampling plan. The subsystems definition will follow along the lines of bulk sampling, surface sampling, and air sampling with interfaces to training and guidance to the sampling staff, microbial analysis plans for the identified agents, data management, and sample archiving. Tradeoff analyses should weigh the different sampling objectives and form the basis for the selection of sampling methods, background characterization instruments, sampling schedule, analysis architectures, and sampling results as input to calculations for exposure risk assessments.

In the development of the plan, several other factors should be considered:

- *Sample handling protocols* would provide procedures that ensure measurement of the physical distribution of the contaminant, and preserve viable material for culture inoculation (White and Fenner, 1994) or viral plaque assay (Litts, 2000; Sambrook and Russell, 2001) for identification and an assessment of virulence. A priori knowledge of the choice of assay will help dictate which wetting agents and elution techniques will be compatible with or detrimental to analysis. For example, salts (such as phosphate-buffered saline) can inhibit PCR efficiency. There are variations among vendor kits for sample cleanup (for example, Idaho Technology, 2004, Qiagen, 2003).
- *Laboratory capability* will determine the ability to work with the proposed sample media (wipes, agar, bulk), analysis throughput, level of analysis, and storage.

- *Collection efficiency* and the anticipated cost of the method would need to consider the number of samples to be analyzed and the need for on-site quantification.
- *Risk assessment* utility would need to be identified for the sampling method to prove the usefulness to the building owner or the agency that has jurisdiction over the project.
- *Other potential uses of collected samples* should be considered if they would require special handling. Special attention would be given to samples for use by law enforcement agencies if maintaining the chain of custody is important.

The general sampling plan should have clearly defined objectives; acceptance criteria for sample and analysis data; a calculation of the number and types of samples desired; and a microbial analysis plan and a risk assessment plan, each statistically rigorous. It is well accepted that several sampling strategies will be required to achieve different objectives (National Response Team [NRT], 2003). Potential sampling objectives might include the following:

- *Preliminary screening of a facility*. The objective is to determine the extent of contamination and the viability of pathogens. Composite samples from large surface areas and air volumes are obtained to maximize the likelihood of finding contamination.
- *Identification of threat agents in bulk material*. The objective is to determine qualitatively whether bulk material, such as dust in HVAC elements or powder in an envelope, is contaminated. Such sampling is also a tool for screening and evidence collection.
- *Determination of contamination of an article*. The objective is to determine whether the surface of an article, such as a book or a telephone is contaminated. Typically, composite surface samples of large articles or individual samples of small articles are collected.
- *Extent and location of contamination (site characterization)*. After the hazardous contaminant is positively identified, further sampling is necessary to determine how far the contamination has spread and what pathogens are still viable. Sampling is performed to determine qualitatively and, if possible, semiquantitatively, the extent and magnitude of contamination. Walls, floors, equipment, and air-handling systems should be sampled. Sampling results also should be used to establish exclusion zones for site control and decontamination.
- *Efficiency of decontaminations*. Biological samplers are used with positive controls, such as spore strips and biological reservoirs (canisters, envelopes, open surface plates) that contain known concentrations of threat proxy microorganisms, along with environmental monitors, such as particle size distribution instruments and background chemical analyzers (gas chromatograph–mass spectrometer to ensure the absence of suppressants).

Sampling Phases

Sampling and analyses performed after an attack should be conducted in three phases, within the context of the general sampling plan.

Phase 1: Confirmation and contamination baseline. The specific nature of the contaminants—identification, microbial stage, and pervasiveness in the building environment—should be characterized and recorded to establish a baseline from which to determine appropriate decontamination approaches. Any substances that might cause suppression or false positives in microbial assays should be identified and quantified before cleanup and disposal actions are undertaken. The baseline determination could lead to gross decontamination of large concentrations of agent with high-efficiency particulate air (HEPA) vacuuming before large-scale remediation begins.

Phase 2: Assessment and characterization. As initial disposal of contaminated materials begins, cross-contamination and contaminant redistribution are inevitable. Regular sampling is necessary not only to follow the progression of the contaminant migration but also to test for contaminant attenuation, reaerosolization, morphological change, and growth potential. Analysis in phase 2 will inform the process of selecting the appropriate decontamination approach and bracket decontamination risk and expectation.

Phase 3: Decontamination effectiveness. Along with the use of positive controls, sampling in phase 3 will quantify the effectiveness of decontamination, verify the extent of residual contamination, and provide data for re-occupancy decisions.

Using Regular Sampling Intervals

Ideally, cost and laboratory support notwithstanding, regular sampling of the contaminated site should begin concurrently with specimen testing of exposed personnel and patients. The sampling schedule for analysis of—air, surfaces, machinery, HVAC, and electronics is necessary for several purposes:

- Presumptive identification
- Establishment of initial loading baselines
- Analysis of agent decay rate and attenuation
- Analysis of diffusion and reaerosolization
- Analysis of redistribution of concentrations
- Discovery of new incubation sites

BOX 9-1
Sensors and Kits for Rapid Identification of Biological Agents
(Presented solely to provide examples of the products available.
No endorsement is implied.)

Redline Alert™ (Tetracore) is an immunochromatographic handheld ticket-type assay that uses lyophilized antigen to indicate by color change positive and negative responses to *B. anthracis.* The color change occurs within a few minutes.

BV™ Test (BioVeris Corporation) is a small test kit that is based on a sandwich immunoassay format. One antibody (specific to the pathogen) is immobilized onto microparticles and mixed with reagents to form a mixture that is transported to an electronic device to emit light. Test kits are available for anthrax, botulinum neurotoxins A, B, E and F, ricin, and staphylococcal enterotoxins A and B.

HANAA (Handheld Advanced Nucleic Acid Analyzer) (Lawrence Livermore National Laboratory) is a handheld unit that can test 4 samples at a time, based on PCR thermocycler techniques. The test amplifies agent-specific DNA fragments in less than 30 minutes.

Bio-Seeq™ (Smith Detection) is a handheld unit that can test 6 samples simultaneously, based on PCR thermocycler technology. It can give an identification in less than 30 minutes.

The sampling interval will depend on the morphology and projected stability of the agent. For example, vegetative cells will require more frequent sampling; spores and toxins might permit longer intervals. The biological agent might have been weaponized or altered in some way, such as by encapsulation. This paradigm will provide useful information for later decontamination selection and procedures. At least 3 identical samples should be taken at each site: the first for handheld kits/sensors for rapid identification, the second for on-site presumptive laboratory analysis with more sophisticated tools, and the third for confirmatory analysis at a designated LRN facility.

On-site rapid identification can be accomplished by one or several of sensors and kits for a small range of biological agents. Commercially available test devices (not endorsed, but listed in Box 9-1 for illustration) are available for many agents. Those devices use a variety of identification technologies and vary widely in their sensitivity and specificity.

Laboratory presumptive testing can follow sentinel (formerly Level A) laboratory procedures. The American Society for Microbiology (ASM) has agreed to take the lead in the development and dissemination of sentinel laboratory infor-

mation (ASM, 2004). The only agent specific guideline, for staphylococcal enterotoxin B, was published in January 2004.

Many of the new ASM guidelines for *B. anthracis* will rely on CDC guidance (CDC, 2001a). CDC recommends presumptive test procedures that include micromorphology by gram stain; microscopic observation of capsule; and routine culture for colonial morphology, hemolysis, motility, and sporulation. Confirmatory procedures include lysis by γ-phage, direct fluorescence assay, antimicrobial susceptibility testing, and the use of advanced technology tools such as time-resolved fluorescence, and PCR testing.

Human specimen samples from, and clinical observation of, people who are potentially exposed also can be part of the general sampling plan. CDC has established laboratory test criteria for the clinical diagnosis of plague (CDC, 2001b) that include clinical and laboratory conditions to be met for suspected, presumptive, and confirmed cases. CDC states (CDC, 2001a) that "serologic tests for potential exposure to *B. anthracis* are currently being evaluated and at this time their clinical utility is not known."

Guidance developed by the International Commission on Microbiological Specifications for Foods (http://www.foodscience.afisc.csiro.au/icmsf.htm) to document the design of sampling plans for microbial pathogens in food also could be useful to consider in this context.

Source Sampling

Close consultation with laboratory personnel is vital for planning effective sampling (Martyny et al., 1999). The type of material to be tested, the biological agents sought, information needed about the agents, and the expected results determine the appropriate collection method. Laboratory and field staff should discuss how much material is required to conduct particular assays, which wetting materials are to be used, the number of samples needed to obtain representative results, the number of samples the laboratory can handle in a day so that sample processing is not delayed beyond an acceptable holding time, and required sample storage and shipping conditions.

Samples to be tested for viable microorganism counts generally require overnight delivery and either must be chilled (maintained between ~4°C and 10°C) or kept at room temperature but protected from extremely high or low temperatures during transport. It must be determined whether samples should be sustained within the physiological pH range (7.0-7.4). In some cases, preservatives or an agent that neutralizes a biocide (sodium thiosulfate for chlorine in water samples) is added in the field to stabilize samples and limit changes before analysis. Some viral agents might need to be stored in an appropriate broth to determine virulence. Culture plates also can be inoculated at the collection site before samples are shipped, and convenient dipslides are available for some types of water testing.

Sampling Methods

Bulk Sampling

Bulk samples can provide information about contaminated regions, microbial sources, and material for later correlation with diagnostic evaluation of people who have been exposed to the agent, although these samples should not be considered good estimators of actual or potential exposure. Bulk samples use portions of environmental materials (settled dust, sections of wallboard, pieces of duct lining, carpet segments, return air filters). It should be noted that, depending on the nature of the potential contamination, the samples should be sent to a laboratory equipped to handle pathogens of the appropriate biosafety level.

The objective of bulk sampling is to collect a portion of material small enough to be transported conveniently and handled easily in the laboratory that still represents the area or object being sampled (Martyny et al., 1999). Testing can be done to determine whether organisms have colonized the material and are actively growing and to identify surfaces where previously airborne contaminants have deposited and accumulated. Some infectious agents that are present in low numbers are difficult to culture from surface or air samples (to some degree because of low extraction efficiencies) and might be best identified from bulk sources (Burge and Solomon, 1987).

Settled dust or dust entrained in return-air filters might contain previously airborne biological particles that provide a more representative picture of exposure than would short-term air samples. Dust collected on return-air filters augments the assumption that collected particles would reflect the airborne materials to which building occupants had been exposed (Burge and Solomon, 1987). Filter deposits also can serve as a growth substrate if filters become damp. However, bulk samples cannot be used in place of air samples: Bulk samples do not accurately reflect past, future, or even current bioaerosol exposures. Researchers who have collected parallel bulk and air samples have seen differences that reflect the presence of different biological agents on surfaces and in the air (Fox and Rosario, 1994).

Bulk samples are cut or otherwise aseptically removed from a source and placed in clean, new or sterilized containers, usually sterile jars for dry items and sterile bottles for water samples. Sealable plastic bags are useful for samples of ventilation duct lining, ceiling tiles, wallpaper, and similar materials. To preserve the integrity of samples and avoid cross-contamination, paper bags can be placed in plastic bags with a packet of desiccant material to keep the sample dry. The amount of sample to collect and the manner in which to remove and transport it will depend on the sample type and the analytical methods to be applied.

Samples of loose material, such as carpet dust for antigen detection, can often be collected with a vacuum device fitted, for example, with HEPA filters and bags.

Depending on how the results will be used, individual areas can be sampled separately or samples can be combined (during collection or in the laboratory). Making composite samples from large areas reduces the number for analysis and can improve the likelihood of detecting the material of interest. Sometimes a square meter of test surface is sampled or a prescribed area is vacuumed for a specified period. The results from the sampling are presented as the amount of biological material per gram of dust for that area. Alternatively, an entire room or building might be vacuumed and the results reported as the average concentration of biological agents in the dust collected for that unit.

Surface Sampling

Surface sampling can be done with wipes, swabs, and HEPA vacuum socks. It is preferred over bulk sampling when a rapid, less costly, and less destructive method of sample acquisition is desired. Along with air sampling, surface sampling allows repeated measurements within the sampling phases mentioned earlier. Because of the three-dimensional nature of surfaces amenable to contamination (walls, ceilings, floors, furniture, equipment, duct work), surface sampling can be used to analyze the initial spatial distribution and the dilution of substance, the redistribution and reaerosolization of contaminants during consequence management, and the effectiveness of decontamination. The concentration and character of biological substances on surfaces depend on many factors, such as particle or droplet size, precipitation rate, and surface affinity. The surface material, history of exposure to moisture, exposure to ultraviolet light, temperature, indoor air circulation, and exposure to background chemicals are additional factors.

The consequence management and decontamination activities resulting from the *B. anthracis* attacks on government and commercial facilities in 2001-2002 have provided a basis for discussion of the merits and uncertainties of surface sampling. The remediation resulted in the issuance of interim guidance for environmental sampling from CDC (CDC, 2002a) and the U.S. Postal Service (USPS).

The preface of "Comprehensive Procedures for Collecting Environmental Samples for Culturing *Bacillus anthracis*" (CDC, 2002b) states that:

> Currently, no occupational or environmental exposure standards exist for *anthracis* spores. In addition, there are presently no validated sampling and analytical methods specifically for *B. anthracis* in environmental samples. Data are lacking on collection efficiency of the sample collection media (swabs, wipes, filters, etc.) for typical porous and non-porous surfaces encountered in indoor environments (e.g., furniture, carpet, letters, clothing, ventilation system filters). The effect of varying concentrations of *B. anthracis*-containing particles and dust loading on sampling efficiency has not been studied. Further, the recovery efficiency of the analytical methods (efficiency of removal of *B. anthra-*

cis spores from the sample collection media) has not been adequately evaluated and limits of detection have not been established.

Providing that objectives are attainable, a general sampling plan can offer guidance for obtaining useful information. The CDC website and 13-page environmental sampling guidance are consistent with information presented to the committee about the successful sampling efforts by the Armed Forces Radiobiology Research Institute (AFRRI, Dr. Greg Knudson) for environmental testing at the Brentwood mail facility, and by the Bio-One solutions LLC (John Mason) for decontamination effort at the American Media, Inc. (AMI) building. The CDC guidance addresses the overall planning (training, safety, record keeping, and documentation); sampling strategy (bulk sampling, surface sampling with wipes or swabs, surface sampling by HEPA vacuuming, air sampling); sample handling (packaging and shipment, sample analysis, sample interpretation); and specific collection procedures, materials, and equipment (bulk sampling, surface sampling with wipes and swabs, surface sampling by HEPA vacuuming, air sampling).

Another important feature of the CDC publication is its emphasis on sample logging (location, time, date, area size, map of sample areas, person collecting) and chain of custody. It is clear that recommendations for procedures are evolving, with the need for peer review and consensus particularly for the threat substances with microbial features inconsistent with anthrax spores.

Surface sampling plans should be reviewed and technical improvements should be identified and subjected to peer review. Skolnick and Hamilton (2004) have commented that the 2001-2002 procedures appear essentially "ad hoc," lacking reference to earlier published works such as the NASA spacecraft testing activity for planetary protection (NASA, 1980). Different agencies recommend different collection procedures, and there are ambiguities in some documents. Areas of divergence include recommendation for swab or wipe material (Dacron or Rayon versus cotton), areas to be sampled (the guidance area is varied and generally too big to avoid overloading by surface debris), collection stroking (vertical, horizontal, rotational combinations), and choice of wetting agent (sterile water, phosphate-buffered saline). Skolnick and Hamilton pointed out several inconsistencies in swab-and-rinse assay procedures specified in interim guidance documents issued by the U.S. Postal Service and the CDC

There is disagreement about whether dry or wet swabs are more effective for surface sampling. The reviewed procedures provide no justification for the use of dry swabs in swab-rinse environmental testing. Moreover, the interagency Brentwood study leads Skolnick and Hamilton (2004) to consider the dry swab data unreliable. In Chapter 3 of this report, the committee cites problems with the use of dry swabs at the Wallingford Connecticut Postal facility, where their use led to a false negative. Subsequent sampling at Wallingford with wet wipes

showed positive results. The results and the reports by AFRRI and BioOne Solutions led this committee to conclude that dry-swab or dry-wipe surface sampling should be abandoned in favor of wet-wipe surface sampling. However, there are few quantitative data for the collection efficiency and biological viability of wet-wipe techniques.

Another area of disparity involves the use of detergent as an additive to the sample rinse to aid spore extraction. USPS did not incorporate its use in its swab-rinse procedure. The volume of rinse used to extract the swab also was different— CDC recommends a 3 milliliter (mL) solution; USPS used a 1.5 mL.

The fraction of the total extract volume inoculated onto culture plates was also differed. CDC used a 1 in 10 ratio; USPS used 1 in 15. Both methods cultured too little of total extract volume for use as a "rule out" assay that should be maximally sensitive to support a "zero" tolerance policy—a policy that itself should be reassessed (Skolnick and Hamilton, 2004).

The authors also question the number of culture plates inoculated per sample (CDC used 3 versus USPS used 1). The culturing of a single plate provides no measure of variation and is not considered good laboratory practice.

A new generation of wetted sponge sampler kits (Edgewood Chemical Biological Center [ECBC], 2004) offers potential improvements in wiping, handling, storage, and elution. The new kit should be tested and evaluated by experts for each class of pathogen (with taxonomic order, for a wide range of environmental backgrounds, and for their compatibility with different assay techniques). Buttner and colleagues (2001) have evaluated the collection efficiency of wetted swabs and wetted sponge wipes for removing *B. subtilis* spores from vinyl floor tile, and from soiled carpet. In trials with and without background contamination with *P. chrysogenum* the criteria for efficiency included the physical sampling loss (up to 7%) and the loss from the microbial analysis (about 25%). The resultant efficiencies were reported as varying from 67% for wet cotton swabs to 74% for the wet sponge wipe. Quantitative PCR analysis was compared with culture analysis, and there was, a discussion of the inhibition of microbial growth in the analyses attributable to non-biological contaminants in the carpet. However, the wetting agent, the volume of extraction rinse, and the amount inoculated onto the culture plate were different enough from those used in other investigations to make comparisons difficult.

Air Sampling

The physical principles of particulate sampling are well established, and the adaptation to sampling for biological agents is rapidly maturing. Air sampling is particularly useful in the determination of biological load within a dynamic environment, where the circulation of the air and the presence of more than one contaminant are factors. Common to all aerosol sampling is the need for efficient

collection that aids quantification of the aerosol concentration—a critical parameter estimating exposure.

Several varieties of air sampler are available, classified by the way in which they deposit particles for analysis:

- *Slit samplers* have rectangular impaction nozzles that deposit particles onto an agar-based medium for incubation or onto a glass slide or tape strip that is examined through a microscope. The collection substrate can be stationary, or it can move continuously or periodically under the slit.
- *Centrifugal samplers* use a particle's inertial behavior—in a radial manner for agar strip impactors and cyclone samplers. Centrifugal sampling also is used to partition particles into a liquid for later analysis.
- *Liquid impingement samplers* use a process that is similar to solid-plate impaction, but inertia forces the particles onto a surface submersed in or washed with liquid. All-glass impingers are widely used because of the gentle nature of physical disruption.
- *Filtration samplers* take advantage of inertial forces, interception, gravitational settling, diffusion, and electrostatic attraction to separate particles from an air stream and deposit them on or within a filter. The filters usually are held in inexpensive cassettes attached to portable pumps. Dry-filter units often use polyester felt filters for frequent retrieval, although impaction and desiccation can reduce the viability of some pathogens. Some of the newer gel filtration systems (Sartorius, 2004) offer the potential for increased viable yield.

Generally, two main considerations involve the choice of nutrient agar for direct culture analysis—particles are forced onto an agar plate for incubation—or the use of filters for the trapping particulate matter before physical disruption and subsequent culture or spore analysis (counting, morphology). For the substance under investigation, research will be necessary to resolve the tradeoffs among the several inertial impaction methods.

The collection efficiency for air sampling is generally divided into three components (Willeke and Macher, 1999):

- *Inlet sampling efficiency* is a measure of the ability of a sampling inlet to entrain particles from the ambient environment regardless of particle size, shape, or aerodynamic behavior.
- *Particle removal efficiency* is a measure of ability to separate particles from the sampled air stream and deposit them on or in a collection medium.
- *Biological recovery efficiency* is a measure of ability to deliver the collected particles to an assay system without altering their viability, activity, physical integrity, or other essential characteristics.

There are many commercially available collectors whose properties and

BOX 9-2
Air Samplers

The following information is presented solely to provide examples of the products available. No endorsement is implied.

Several collectors can be used to capture particles in a broad range of sizes. The devices have 450-1000 liters-per-second flow rates and can be used to sample the air in a medium-sized room in hours rather than the days required by low-flow-rate devices:

- SpinCon (Sceptor Industries, http://www.sceptorindustries.com/product/spincon.htm)
- Universal Air Sampler (Applied Physics, USA, http://www.appliedphysicsusa.com/uas_moudi.html)
- Dry filter unit (http://www.dcfp.navy.mil/library/cbrdnews/DFUTip001.htm)

If analysis of particles in a specific size range is required for a smaller area, such as the inside of an air duct during decontamination, it is more appropriate to use a size-segregating cascade device:

- Graseby-Anderson Mark III Cascade Impactor http://www.cleanair.com/Services/Analytical/Serv_Prices/anderson_size.html)
- Sioutas (http://www.sceptorindustries.com/product/spincon.htm)

specifications (particle size range, flow rate, collection media) must be matched to the sampling plan and objectives (Box 9-2). For example, it can take 40 hours for smaller particles—in the range of 0.5 micrometers (μm) to 1 μm—to settle; 10-μm particles will settle in a few minutes. Initial assessment and characterization of the severity of an attack requires information about the size range of particles, and that process requires a calculation of how much is resuspended, for example, by large-volume blowers.

FINDINGS AND RECOMMENDATIONS

Finding 9-1
General Centers for Disease Control (CDC) sampling guidance exists for *Bacillus anthracis* spores, but there is no official guidance for the collection of vegetative *B. anthracis*, plague bacteria, or smallpox virions.

Recommendation 9-1
Sampling protocols must be appropriate to the threat. Sampling for *B. anthracis* spores should be done according to published guidance from CDC and the Na-

tional Institute for Occupational Safety and Health. The CDC and the American Society for Microbiology should develop sampling and analysis guidelines for the other threat agents. Other agencies (such as the EPA and the FBI) that may be involved in sampling also should be consulted.

Finding 9-2
Surface sampling with dry wipes led to false negatives at the Wallingford postal facility and to inconlcusive results at the Brentwood postal facility.

Recommendation 9-2
Dry-wipe and dry-swab surface sampling should be abandoned in favor of wet-surface swipe techniques. HEPA vacuum surface sampling should be continued as complementary to surface swiping.

Finding 9-3
Different threat substances require different sampling protocols. The variety of collection approaches currently in use results in widely varying collection and extraction efficiencies, which hamper attempts to quantify the initial extent of contamination.

Recommendation 9-3
Sampling and analysis should be standardized. Research should assess the efficiency of collection and analysis for each type of biological agent. Unless the sampling efficiency is known, the amount of contaminant deposited cannot be estimated with confidence.

Finding 9-4
There is consensus within the federal government regarding the value of a general sampling plan to guide the use of various surface-, air-, and bulk-sampling methods.

Recommendation 9-4
The general sampling plan should be the result of the consensus of facility stakeholders; medical, public health, and environmental experts; decontamination technologists; laboratory analysts; and worker safety representatives. It should encompass three phases: (1) confirmation and contamination baseline, (2) assessment and characterization, and (3) decontamination effectiveness. Some sharing of expertise will be necessary for all groups to be well enough informed to come to consensus.

REFERENCES

ASM (American Society for Microbiology). 2004. Detection and Treatment—Sentinel (Level A) Laboratory Guidelines. [Online] Available at: http://www.asm.org/policy/index.asp?bid=667

Bohm, R. 1990. Resistance, survival, sterilization and disinfection of spores of *Bacillus anthracis*. Salisbury Medical Bulletin, Special Supplement 68: 99-101.

Burge, H.A., and W.R. Solomon. 1987. Sampling and analysis of biological aerosols. Atmospheric Environment 21(2): 451-456.

Buttner, M.P., P. Cruz-Perez, and L.D. Stetzenbach. 2001. Enhanced detection of surface-associated bacteria in indoor environments by quantitative PCR. Applied and Environmental Microbiology 67(6): 2564-2570.

CDC (Centers for Disease Control and Prevention). 2001a. Approved Tests for the Detection of *Bacillus anthracis* in the Laboratory Response Network (LRN). [Online] Available at: http://www.bt.cdc.gov/agent/anthrax/labtesting/approvedlrntests.asp.

CDC. 200b. Laboratory Test Criteria for Diagnosis of Plague. [Online] Available at: http://www.cdc.gov/ncidod/dvbid/plague/lab-test-criteria.htm.

CDC. 2002a. Surface Sampling Methods for *Bacillus anthracis* Spore Contamination. [Online] Available at: http://www.cdc.gov/ncidod/EID/vol8no10/02-0382.htm.

CDC. 2002b. Comprehensive Procedures for Collecting Environmental Samples for Culturing *Bacillus anthracis*. [Online] Available at: http://www.bt.cdc.gov/agent/anthrax/environmental-sampling-apr2002.asp.

CDC. 2004. The Laboratory Response Network (LRN) for Bioterrorism. [Online] Available at: http://www.bt.cdc.gov/lrn/factsheet.asp.

ECBC (Edgewood Chemical Biological Center). 2004. The Next Generation-Self-Contained Biological Sampling Kits (BiSKit). [Online] Available at: http://www.edgewood.army.mil/ps/features/biskit.pdf.

Fox, A. and R.M.T. Rosario. 1994. Quantification of muramic acid, a marker for bacterial peptidoglycan, in dust collected from hospital and home air-conditioning filters using gas chromatography. Mass Spectrometry. Indoor Air 4: 239-247.

Idaho Technology. 2004. DNA Purification Methods. [Online] Available at: http://www.idahotech.com/reagents/it123dnakit.html.

Litts, J. 2000. Plaque Assay Methods. [Online] Available at: http://www.baculovirus.com/protocols/plaque_assay.htm.

Martyny, J., K.F. Martinez, and P.R. Morey. 1999. Source Sampling. Ch. 12 in Bioaerosols: Assessment and Control, J. Macher, ed. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists.

NASA (National Aeronautics and Space Administration). 1980. NASA Standard Procedures for the Microbial Examination of Space Hardware. Washington, DC: NASA.NPG: 5340.1d

NRT (National Response Team). 2003. Technical Assistance for Anthrax Response. National Response Team Interim-Final Draft, Phase I Update. Washington, DC: National Response Team.

Qiagen. 2003. Approach to DNA Cleanup and Concentration. [Online] Available at: http://www1.qiagen.com/literature/handbooks/INT/cleanlit.aspx.

Sambrook, J. and D. Russell. 2001. Molecular Cloning: A Laboratory Manual. Third Edition. Cold Spring Harbor, New York: CSHL Press.

Sartorius. 2004. A Gel-Based Air Sampler. [Online] Available at: http://www.sartorius.com/en/biotechnology/laboratory/products_applications/microbiology/products/Lprod97.shtml

Skolnick, E.B., and R.G. Hamilton. 2004. Legacy science suggests improved surface-testing practices for detection of dispersed bioagents in bioterrorism response. Presentation to the 2004 National Environmental Monitoring Conference: Washington, DC.

Turnbull, P. 1990. Anthrax. Pp. 364 in Topley and Wilson's Principles of Bacteriology, Virology and Immunity, 8th Edition. Vol. 3. G.R. Smith and C.R. Easmon, eds. Sevenoaks, England: Edward Arnold.

Wherle, P.F., J.J. Posch, K.H. Richter, and D.A. Henderson. 1970. An airborne outbreak of smallpox in a German hospital and its significance with respect to other recent outbreaks. Bulletin World Health Organization 43: 2230-2251.

White, D.O. and F.J. Fenner. 1994. Medical Virology. San Diego, California: Academic Press.

Willeke, K., and J.M. Macher. 1999. Air Sampling. Ch. 11 in Bioaerosols: Assessment and Control, J. Macher, ed. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists.

10

Decontamination Practices and Principles

PROCESSES FOR DECONTAMINATION OF HARMFUL BIOLOGICAL AGENTS AND OTHER RESPONSE OPTIONS

Four key phases—assessment, planning, decontamination, and verification—can be identified in the response to an act of bioterrorism. Depending on the circumstances, those phases might vary in length, and they can comprise simple or complex tasks.

The first task within the assessment phase, after biological contamination has been discovered, is to map the contaminated area. The second step is to identify the agent's physical and biological properties: was it spread as a liquid or powder? Has it been physically treated to increase its virulence or ability to be resuspended in the air? Has it been genetically engineered to resist drug treatment? Answering those questions is likely to require extensive sampling of the contaminated area.

Proper planning—the second phase—is crucial to the success of decontamination, and time spent there will be amply rewarded later. Several important decisions must be made and major tasks accomplished before decontamination can begin:

- The decontamination method must be selected.
- Verification methods must be chosen.
- The scientific criteria for success must be defined.
- Personnel from companies or government agencies with the proper expertise to plan and execute the decontamination must be identified or hired.
- A mechanism for community liaison and involvement must be established.

• Technical questions—simple and complex—about a variety of issues, such as what to do with wastewater from worker decontamination baths and where to place testing apparatus during the decontamination process, must be answered.

The actual decontamination operation of a building is likely to be conducted in a few days, although the schedule depends on the size of the project and its complexity. Temperature, relative humidity, concentration of decontamination agent, and contact time typically must be measured and recorded during decontamination. The success of the operation, however, and the avoidance of major technical or public relations problems, will largely depend on the quality of the planning.

Two strategies can be used to verify successful decontamination. If the contaminant has been physically removed, for example by high efficiency particulate air (HEPA) vacuuming, verification will need to rely on the second method. If the contaminant has been left in place but inactivated, then environmental sampling after the decontamination is the most direct testing method. Direct validation of procedures that remove the contaminant is difficult. Direct validation is the demonstration that signatures of the original organism are still present—as determined by antibody binding or DNA hybridization assays—but that the samples are culture negative. The presence of actual target organisms in a place where samples are collected cannot be confirmed in the absence of such data. A culture test, in the absence of signature validation, cannot defend against the challenge that a collection was culture negative only because the collection process missed the target organisms. Results can be compared with those obtained before the procedure and against the standard specified as being "clean enough" to warrant a halt to further decontamination. A detailed sampling plan should be in place beforehand, including specific locations to be sampled, so that results will be useful and significant once they are known.

A second strategy for validation is the use of surrogate organisms, or spore strips with defined numbers of spores on each strip. The test strips are placed in various locations before remediation and tested for viability afterward. That validation is best suited for fumigants and not appropriate for liquid preparations (Box 10-1).

Although the committee was not asked to recommend specific methods for decontamination, the four steps listed here are so intertwined that the committee could not reasonably deal with assessment, planning, and verification without also considering decontamination. Moreover, the committee hopes that this report will be helpful to any facility manager who must cope with biological contamination. The discussion of decontamination methods presented here should provide a summary of the issues involved in choosing an approach.

Decontamination methods can be classified into three categories—vapor-phase treatment, reactive-solution treatment, and physical decontamination. Many

BOX 10-1
Acceptable Kill Levels

A question that must be addressed is, "What level of killing efficiency is sufficient?" As with many real-life issues, the answer to this important question depends on many factors. For example, let's say a 100,000 sq. ft. building is contaminated with 1 gram of anthrax. If 1 x 10^{12} spores were uniformly spread over all surfaces, there might be 1 x 10^{6} to 1 x 10^{7} spores/sq. ft. Decontamination verified with spore strips might establish a 1 x 10^{6} kill rate. Confirming that all potentially viable spores had been removed would be impossible unless more sensitive spore strips were used. A spore per square foot might still be present. Furthermore, spores do not have uniform susceptibility to a decontaminating agent and their susceptibility varies depending on the surface dryness, spore wall thickness, and exposed surface area (clumping, imbedded in other material). In addition, surface sampling in buildings that were subject to a *B. anthracis* attack clearly show nonuniformity in the distribution of spores. Therefore, using a simple "bright line" of six log kill efficiency may not be applicable in all situations.

Illustration of a Six-log Kill

Initial contamination, 1.0 g of dried *Bacillus anthracis* spores:
1,000,000,000,000 Spores
↓
90% reduction of this challenge leaves:
100,000,000,000 spores
↓
A six log kill, 99.9999% efficiency leaves:
1,000,000 spores

With an estimate of 10,000 spores per lethal dose, that leaves 100 lethal doses. Clearly the level of remediation required is a function of the initial concentration. This demonstrates the importance of identifying the source term and conducting initial gross decontamination prior to fumigant operations.

methods have been developed in each category, but not all are suitable for use in large facilities such as office buildings or airports. Some of the latest technologies are described in the following section.

DECONTAMINATION OF HARMFUL BIOLOGICAL AGENTS BY CHEMICAL AND PHYSICAL METHODS

Decontamination of buildings and their contents requires the inactivation or removal of biological agents. Decontamination of an entire building presents complex problems because some components or contents of a building could be resistant to treatment with specific chemical decontaminants whereas others might

be especially susceptible to treatment. The design and construction of a building also can influence the efficacy of the effort. If the contaminant is a particulate substance, and the decontamination method does not contact all contaminated surfaces, the potential for subsequent release of untreated contaminants will remain even after the building reopens. Any chemical decontaminant must penetrate and permeate every part of a contaminated building. Hence, gas phase decontamination of buildings would seem to be the best method. Because of the extent of the potential loading of infectious particulates on objects in an office building, there also might be a need to decontaminate surfaces by treating them with liquid formulations of decontaminants, such as sodium hypochlorite (household bleach) solutions or one of the newly developed compounds designed for direct contact use. Another preferred method of gross decontamination is vacuum cleaning with HEPA filtration to reduce the particulate load sufficiently to allow effective remediation by a fumigant. HEPA vacuuming, combined with a vaccination program for facility occupants, has been proposed as an alternative to fumigation for facilities in which there is a stable population (Weis et al., 2002). More research in this area is warranted. Although HEPA filtration also could work in some circumstances, it is not likely to be completely effective in a large public building, such as an airport, because of the large open indoor spaces.

The next two sections discuss two types of the various decontamination methods: vapor phase and reactive solution treatments. For each type, selected treatments are described in detail as examples. Other aqueous-based, exposed-surface decontamination reagents, such peroxyacetic acid, peroxyacetic acid/hydrogen peroxide, calcium hypochlorite, and Vikon S, are available and discussed in "Biological Restoration Plan for Major International Airports," (LLNL, 2005).

Vapor Phase Treatments

Chlorine Dioxide

Chlorine dioxide (ClO_2) is a gas at room temperature that is a reaction product of sodium hypochlorite, hydrochloric acid, and sodium chlorite or of sodium chlorite and chlorine. ClO_2 is an oxidizing agent that reacts with a wide range of materials. It is used to bleach pulp for paper, and it is coming into more wide use as a disinfectant in water treatment. It has been used to sterilize surfaces in food production facilities. Delivery methods include ClO_2-generating systems that pump polymer bags full of the gas to sterilize the contents has been used as an industrial surface sterilizer (Barrett et al., 2002), and it was used to disinfect a large office building contaminated with *Bacilus. anthracis* spores (USPS, 2002a,b). ClO_2 disrupts proteins and interferes with protein synthesis in bacteria, and it inactivates the outer protein structures of viruses. Its use as a decontaminant is a mature technology and is available for small to large-scale applications.

Sterilizing entire office buildings with ClO_2 is complicated. Several develop-

ment issues were discovered when ClO_2 was used in remediating the Hart Senate Office Building and the Curseen-Morris Mail Processing and Distribution Center (formerly known as the Brentwood postal facility) in Washington, D.C., in the wake of the 2001 *B. anthracis* attack. Even though the gas is short-lived, care must be taken to neutralize any residual gas before treated facilities can be reopened. Because of its reactivity, the residual gaseous material could be entrained in a wastewater stream and disposed of as liquid waste.

ClO_2 can be generated onsite for specific applications. According to the testimony to the Committee on Science of the U.S. House of Representatives (Nov. 8, 2001) of Charles Haas—L.D. Betz Chair Professor of Environmental Engineering at Drexel University—the generating system used affects the purity of the ClO_2 gas (Haas, 2001). Current applications of ClO_2 for building remediation require 75% relative humidity and an exposure of 9000 ppmv hr^{-1}. This is the equivalent of a 10-h exposure with 900 ppmv of the gas.

Industrial uses of ClO_2 include microbial control in food processing, food equipment sanitization, and wastewater and drinking-water treatment. It also has been used to sanitize air ducts and to sanitize and disinfect hospitals. Building sterilization with ClO_2 (or any other appropriate gas) will be a specialty requirement best handled by approved vendors familiar with the hazards of its use. The experience at the Curseen-Morris Mail Processing and Distribution Center showed that sterilization of mail would require large volumes of the gas, so the cost for long-term use would be prohibitive.

The U.S. Food and Drug Administration has approved the use of ClO_2 as a disinfectant in the food service industry and as a surface sterilant for processed foods. The U.S. Environmental Protection Agency (EPA) has approved its use in water. The decontamination of the Hart Senate Office Building and the Curseen-Morris Mail Processing and Distribution Center apparently was successful, but the use of ClO_2 was permitted only by a special exemption granted by EPA. Evaluation of the lessons from those incidents is an important part of the consideration for its future use in facility decontamination and for its ultimate approval for such use "routinely" by EPA. The Occupational Safety and Health Administration (OSHA) sets maximum allowable concentrations for ClO_2 exposure in workers; EPA and state regulatory agencies will regulate its release into the open air. Short-term environmental effects are possible if the gas escapes containment during use in a facility. ClO_2 is an irritant to the eyes, lungs, and skin, and concentrations in excess of 5 ppm are considered immediately dangerous to life and health. Adequate removal of ClO_2 must be ensured before facilities can be reoccupied.

A major operational effect of the decontamination of buildings by gas phase sterilants is the required shutdown of the facility. Facilities must remain closed until both decontamination of the biological agent and the complete removal of the ClO_2 have been demonstrated. Additional operational issues could become obvious from the experience the Hart Senate Office Building and at the Curseen-

Morris Mail Processing and Distribution Center. Careful documentation and evaluation of those experiences will provide important information about the use of ClO_2. The concerns of nearby residents and business operators also can dramatically influence the application of ClO_2 at a given site.

Because ClO_2 was used to decontaminate the affected buildings, there are precedents and data to lead the future applications of this technology to facility decontamination.

Ethylene Oxide

Ethylene oxide (EtO) is a sterilant gas that can be delivered from bulk sterilizers (similar to autoclaves) or in prepared packages that contain measured volumes. EtO has for many years been used to sterilize medical equipment and heat-labile materials. It also is used widely as a fumigant for delicate or rare objects and books. EtO alkylates proteins in bacteria and viruses to disrupt protein functions and inactivate cells. Its use as a sterilant is a mature technology that is currently available through a variety of vendors. Large-scale facility decontamination could be difficult because of the need to remove residual EtO after decontamination is complete. Significant permitting and emissions requirements will affect its implementation. A long lead time will be needed before this technology can be implemented to decontaminate office buildings. There could be specific small-scale applications (using ethylene oxide retorts) for the decontamination of small, irreplaceable items, such as letters or other documents, electronic media, and photographs that have a "shelf-life" of utility in a business application or that are essential to the business.

Industrial uses of EtO include sterilization of hospital equipment and supplies, especially items that cannot be subjected to heat or pressure, such as fiberoptic scopes. Gas purity is not an issue because that would be the responsibility of the vendor. Although approved by the Food and Drug Administration for use in sterilization of medical equipment, its use as a facility decontaminant would be a new application and thus subject to evaluation for the specific requirements. EPA also could have to set guidelines for the use of EtO in the quantities expected to be necessary for building decontamination. Although it is likely to perform acceptably in a building environment, the concomitant health risks could prove insurmountable. EtO is an irritant to the eyes, lungs, and skin. Women exposed to low concentrations could be at risk of reproductive effects. Use of EtO in bulk quantities also will trigger air quality permit requirements, including those of the Clean Air Act. And because of fire and explosion hazards and the potential carcinogenicity of the compound, there could be even more severe regulatory constraints on its use. The costs associated with all aspects of the use of EtO will be high, especially considering the large quantities required for bulk decontamination.

EtO seems less practical as a vapor phase decontaminant than ClO_2. There is already a precedent for successful use of ClO_2 and the risks associated with EtO are significant. In addition, because EtO alkylates protein substituents and DNA bases, it is classified as a carcinogen and long-term medical monitoring of potentially exposed people would be required.

Methyl Bromide

Methyl bromide (MeBr) is a colorless, gaseous pesticide primarily used for soil fumigation, postharvest protection, and quarantine treatments (USPS, 2002a,b). It is also used to control insects, nematodes, weeds, and pathogens in more than 100 crops, in forest and ornamental nurseries, and in wood products. Annually, 6% of the MeBr used in the United States is for fumigating warehouses, food-processing plants, museums, antiques, and commercial vehicles. For insect control, large buildings are sealed to prevent the fumigant from escaping. MeBr is an EPA-registered pesticide that has been proven effective in fumigating large buildings, including those in urban settings, such as flour mills infested with insects. MeBr is effective against higher organisms, but it has not been used against bacteria. Because it has been identified as an ozone-depleting chemical, and its use in the United States will be phased out by 2006, its applicability is limited even if it were proven effective against bacteria and viruses. Because of its toxicity, storage of the quantities needed to decontaminate a building of any size would create a potential hazard.

There are no documented cases of the efficacy of MeBr for eradicating *B. anthracis*. Where MeBr was used to decontaminate harvesting equipment of karnal bunt (a fungal disease of wheat), only 90% of the fungal spores were eliminated. Its efficacy against fungal spores depended on the life cycle of the spores, and it was most effective against germinating spores. It is also an effective nematocide. Preliminary efficacy trials have been conducted at the University of Florida on *B. anthracis* surrogates.

MeBr vapor is toxic to humans; inhalation causes dizziness, headache, nausea, vomiting, abdominal pain, mental confusion, tremors, convulsions, pulmonary edema, and eventually coma. Death from respiratory or circulatory collapse can occur. Human exposure to this compound is clearly not acceptable, although it is inexpensive and is widely available. As the date approaches for its phase-out, costs likely will increase and availability will become less certain. EPA could allow emergency use as a fumigant on a case-by-case basis, but inventory of the gas could then become problematic.

If a facility were to be decontaminated with MeBr, the building would not be able to reopen until it could be demonstrated that the biological agent and all residual MeBr gas were completely removed.

Ozone

Ozone (O_3) is a powerful, naturally occurring oxidizing agent with a long history of safe use in the disinfection of municipal water, process water, bottled drinking-water, and water in swimming pools (USPS, 2002a,b). Recent applications include treatment of wastewater, water theme parks, and home spas. Ozone is formed by high-energy-induced disproportionation of oxygen (O_2). In nature, ozone is formed by ultraviolet irradiation and lightning discharges; commercial generators use high electrical voltage to form ozone. Studies on the sporicidal action of ozone indicate that spores of *Bacillus* spp. are more susceptible to ozone than to hydrogen peroxide, and at 10,000-fold lower concentration (Weis et al., 2002). The outer spore coat layers have been shown by electron microscopy to be the probable site of action of ozone.

The U.S. Department of Energy (DOE) Idaho National Engineering and Environmental Laboratory (INEEL) is collaborating with the O3zone Company (a potato-harvesting-equipment maker) to determine the efficacy of destroying *B. anthracis* with ozone (INEEL, 2002). O3zone's technology generates ozone gas by a high-energy electrical current that breaks oxygen molecules into separate atoms. INEEL reported that "simulated anthrax spores" exposed to a high concentration of ozone (10,000 ppm) for about an hour were completely neutralized (Eng, 2002). A research group at San Diego State University was awarded a National Science Foundation research grant in April 2002 to study the effectiveness of ozone for killing *B. anthracis* (Hoskins, 2002).

According to EPA, ozone has been used extensively for water purification, but ozone chemistry in water is not the same as that in air. High concentrations of ozone in air are sometimes used for chemical or biological decontamination of unoccupied spaces and to deodorize spaces during restoration after a fire. However, little is known about the chemical by-products of those processes. Vendors claim that ozone kills mold spores, but there is no definitive information about its efficacy against *B. anthracis*. There are numerous vendors of ozone generators.

OSHA limits human exposure to ozone in air to 0.1 ppm for continuous exposure during an 8-h period and to 0.3 ppm for a 15-minute period. At 1 ppm, ozone is irritating to the eyes and throat. Unstable in water, ozone decomposes to oxygen (its half-life in solution is about 20 minutes). Thus, maintaining effective concentrations of ozone in water is difficult. However, ozone is an effective disinfectant of water and could be an effective gaseous sterilant. Ozone is 1.5 times more powerful as an oxidizing agent than is chlorine and 3000 times more powerful than hypochlorous acid. Its antimicrobial action occurs 4-5 times faster than is possible with chlorine. There have been some reports that indicate ozone's sporicidal activity of ozone; however, its effect on *Bacillus* spp. spores varies with the strain. Ozone could harm or destroy many items found in a contaminated building because it is a strong oxidant. EPA approval presumably would be required for its use.

If a facility were to be decontaminated with ozone, the building cannot be reopened until it could be demonstrated that the biological agent and all residual ozone were completely removed. Building decontamination with ozone does not appear practical because of the lack of demonstrated effectiveness against *B. anthracis* spores and because of the damage it could cause to objects inside a contaminated building.

Paraformaldehyde

Paraformaldehyde, or polymerized formaldehyde, is obtained by concentrating formaldehyde solution. Heating paraformaldehyde powder depolymerizes it to produce formaldehyde gas. Formaldehyde gas is widely used as a fumigant in the poultry industry. As a fumigant, paraformaldehyde kills all microbial forms of life. Past uses of paraformaldehyde include surface sterilization and detoxification (USPS, 2002a,b). It is known to eliminate *B. anthracis* and other infectious agents and toxins. After treatment, the gas is rapidly dissipated by aeration.

Paraformaldehyde is used throughout the world in hospitals, biomedical facilities, veterinary settings, pharmaceutical manufacture, research organizations, and universities. For sterilization, formaldehyde gas exposure for 16 h at a concentration of 1.0 mg L^{-1} at 75% ± 5% relative humidity, and ambient temperature of 75 ± 5 °F is recommended. Information about effectiveness available from the presentation made by Manuel S. Barbeito to the House of Representatives (Barbeito, 2001), and in fact sheets developed by Timothy P. Gouger (U.S. Army Corps of Engineers) and Manuel S. Barbeito (biological safety consultant, Frederick, Maryland, and former Industrial Health and Safety Directorate, U.S. Army, Fort Detrick, Maryland). Formaldehyde gas has been used to decontaminate numerous Biosafety 3 and 4 Laboratories before maintenance, renovations, or changes in research programs. Paraformaldehyde also was used in 1989 to decontaminate a textile mill in Pennsylvania (Phillip Brachman, Emory University, 2004, personal communication).

Paraformaldehyde has been used to eliminate infectious pathogens. In experiments performed by Taylor, Barbeito, and Gremillon, formaldehyde gas treatment was completely successful in sterilizing laboratory facilities, materials, and equipment known to be contaminated with several organisms, including *Clostridium botulinum*. There were no problems with repolymerization or other residues when the concentration and humidity were controlled. Mechanical, electronic, and optical equipment showed no visible or operational effects as a result of treatment.

There are toxicity issues with regard to human exposure. Due to the suspected carcinogenic and toxic nature of paraformaldehyde, any building treated with paraformaldehyde must have formaldehyde gas neutralized with ammonium biocarbonate and be properly ventilated, or have a specially designed ventilation system. The EPA classifies formaldehyde as "Group B1," that is, a probable

human carcinogen of medium carcinogenic hazard. Breathing in contaminated air can be extremely irritating to the eyes, skin, and mucus membranes of the upper respiratory tract and can cause nausea and vomiting. Pulmonary edema and allergic respiratory and skin reactions have also been reported. Buildings decontaminated with formaldehyde gas would be subject to air quality monitoring requirements. Paraformaldehyde fumigation may not be viable for building decontamination because of concerns about its potential carcinogenicity unless the EPA grants special waivers or additional research allays these concerns.

Although there are contradictory opinions regarding the harmful nature of paraformaldehyde towards humans, paraformaldehyde is widely used in the decontamination of microbial and tissue culture hoods at the National Institutes of Health, the U.S. Army Medical Research Institute for Infectious Disease (USAMRIID), and many other locations through out the world. The effect of paraformaldehyde on humans should be further assessed due to the historical efficacy of this chemical in killing bacterial spores.

Vapor Phase Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is an oxidizing agent used in industry for pulp, textile, and environmental applications. It is typically provided as concentrated solutions of 30% for industrial applications; dilute solutions (3 to 10%) are commonly used in medical practice as cleansers for minor cuts. Hydrogen peroxide, its superoxide ion radical, and its hydroxyl radical are intermediate products in the reduction of oxygen in water. The hydroxyl radical is said to be the strongest oxidant known, and it is by this mechanism that hydrogen peroxide is believed to kill bacteria. The hydroxyl radical attacks membrane lipids, DNA, and other essential cell components. Vaporized hydrogen peroxide, a low-temperature sterilant, is created by a machine—a "generator"—and is often used as an antimicrobial pesticide (described below) for decontaminating sealed enclosures such as scientific workstations, isolators, pass-through rooms, medical and diagnostic devices, and for other biological safety applications.

Vapor phase H_2O_2 generators are used to sterilize medical devices and equipment and have application in barrier isolators used in pharmaceutical manufacturing environments, for product sterility testing. The largest volume thus treated to date is 950 m^3. It is not clear if this technology can be scaled up effectively to treat typical buildings and this is a potential research area. There are some concerns about detonation of vapor phase H_2O_2, but this area requires extensive investigation. Vendors claim that vapor phase H_2O_2 has been proven to be effective in biosafety cabinets, isolators, rooms and suites of rooms up to 950 m^3 in size, but this has yet to be substantiated in the open literature. There are several sizes of H_2O_2 vapor generators for various sized spaces. Some spaces can be decontaminated with fully automatic control.

Vapor phase H_2O_2 was successfully used for building remediation at the

Sterling, Virginia mail sorting facility, but has not been approved by the EPA for treating large volumes of air. Unlike chlorine dioxide which requires high humidity, vapor phase H_2O_2 requires relatively low humidity prior to initiation of fumigation activities. Due to the relatively large size of the postal facility, the area was sectioned prior to the application of H_2O_2 for decontamination.

Reactive Solution Treatments

L-Gel (Oxone)

L-Gel is a decontamination method developed at the Lawrence Livermore National Laboratory that uses a single reagent as its primary active ingredient (Barrett et al., 2002; O'Connor et al., 2001; Raber, 2002). The reactive agent is Oxone [potassium peroxymonosulfate] (DuPont, 1998). This is combined with a silica-based gelling agent. This gelling agent makes the compound thixotropic, allowing the reactive component to remain in contact with vertical surfaces and ceilings. It does not harm carpet materials or painted surfaces. A potential drawback is that its formulation will prevent its penetration into fissures and other places that particulate contaminants may have reached. As a surface decontaminant, L-Gel has been demonstrated to be effective on test batches of actual materials that might be found in an office environment. However, publication on its effectiveness for an office environment that contains a wider variety of materials has not yet been found. Some analytical data have been presented (see O'Connor et al., 2001; Raber, 2002; Raber et al., 2001).

Sandia Decontamination Formulations

Aqueous-based decontamination formulations were developed by researchers at the DOE's Sandia National Laboratories. The researchers hoped to find a universal decontaminant for neutralizing both chemical and biological agents. The formulation, whose main active ingredient is hydrogen peroxide, can be used as foams, liquid sprays, or fogs (Modec, 2002). DF-100, more commonly referred to as "Sandia Foam," is now available commercially.

DOE funded the development of the foam as part of its larger Chemical and Biological Nonproliferation Program. The word "foam" is a misnomer because the chemical can be supplied or created as a foam, liquid, or aerosol. Sandia Foam is currently being marketed under the trade name, EasyDECON™, by EnviroFoam Technologies, one of the two current suppliers. How the foam kills spores (bacteria in a rugged, dormant state) is not well understood. It is thought the surfactants perforate the spore's protein armor and allow the oxidizing agents to attack the genetic material inside.

Tests conducted at Sandia showed that the foam destroyed simulants of VX, mustard, Soman, and anthrax (Modec, 2002). Sandia states that the foam is non-

toxic and noncorrosive. Respiratory protection may be required if workplace exposure limits are exceeded. The manufacturer claims that the foam reduces environmental hazards to the point where the effluent may be disposed of "down the drain." The foam is nonflammable and advertised as a dual-use fire-fighting foam and chemical and biological decontaminant. However, the high-expansion Aqueous Film-Forming Foam—a fire-fighting foam—must be stored and treated as hazardous material.

In October 2000, Sandia was funded by DOE to develop an enhanced version of DF-100 to optimize performance for military and civilian first responders (Modec, 2005). This resulted in the new decon formulation, DF-200 (Modec, 2002). Based on test data, a 99.99999% kill of anthrax stimulant is achieved after 30 minutes exposure. This compares with a 99.99% kill for DF-100 in the same time period. Modec, Inc. has been licensed by Sandia to produce DF-200 commercially. Modec sells this product as MDF-200 and commercial production began in December 2001.

Decon Green

Decon Green is a decontamination solution developed by the U.S. Army to detoxify chemical and biological warfare agents (Haley, 2004; Wagner, 2004). The primary ingredients are propylene carbonate, hydrogen peroxide, and Triton X-100, which are mixed together at time of use. Additional ingredients include sodium molybdate and sodium carbonate. Tests have demonstrated that the solution can decontaminate surfaces contaminated with up to 2.5×10^8 *B. anthracis* spores after a 15-minute contact time.

Hypochlorite Solutions

Hypochlorite is the reactive component of chlorine bleach and is an effective decontamination solution (Barrett et al., 2002). Hypochlorite is an oxidizing agent and can react directly with the proteins and membranes of living organisms.

The primary disadvantage of chlorine solutions is their corrosiveness and the mildly reactive residues left after the liquid evaporates. Calcium hypochlorite is a powerful oxidizing agent, and it is highly corrosive. The corrosiveness increases as the temperature rises. Therefore, calcium hypochlorite should not be used to decontaminate sensitive electrical or electronic equipment on aircraft, weapons materials, navigation instruments, or similar equipment. This is especially true where steam is used. Sodium hypochlorite is the commonly available solution known as household bleach. It is also highly corrosive. Synonyms for calcium hypochlorite include Losantin, hypochlorous acid, calcium salt, BK powder, Hy-Chlor, chlorinated lime, lime chloride, chloride of lime, calcium oxychloride, HTH, mildew remover X-14, perchloron, and pittchlor. Synonyms for sodium

hypochlorite include Clorox, bleach, liquid bleach, sodium oxychloride, Javex, antiformin, showchlon, chlorox, B-K, Carrel-dakin solution, Chloros, Dakin's solution, hychlorite, Javelle water, Mera Industries 2MOm3B, Milton, modified Dakin's solution, Piochlor, and 13% active chlorine.

EXAMPLES OF DECONTAMINATION: HART SENATE OFFICE BUILDING AND AMERICAN MEDIA INTERNATIONAL BUILDING

When the use of high containment laboratories for biological warfare research was terminated at Fort Detrick, Maryland, in 1969, paraformaldehyde was used extensively for decontamination of more than 100 buildings. The facilities were decontaminated at least twice. The first decontamination focused on the primary locations where pathogens were used. Then the entire building was decontaminated in a coordinated effort that included decontamination of all spaces within the walls of each building (for example, attic spaces, utility rooms, offices, restrooms, walk in incubators, refrigerators, change rooms, elevators, filter plenums, entire effluent drain system, and other utility lines).

In the recent "bioterror" incidents, chlorine dioxide was the method of decontamination when the Hart Building was exposed to anthrax spores. After the realization that anthrax was the contaminant, a "screening/sampling" effort began almost immediately. This effort was intended to map the extent of contamination. Screening sampling was followed by thorough "characterization sampling," which was intended to identify all areas that would require decontamination and to help identify the best decontamination method to use. That process identified ClO_2 as the best option, followed by formaldehyde gas. Rather than fumigate the entire building with ClO_2, which would have been very difficult, areas known to be heavily contaminated were fumigated first, followed by treatments of other areas as needed (Box 10-2).

Test runs on the ability of ClO_2 to kill anthrax surrogate spores were conducted and they showed that ClO_2 effectively kills such spores at 75°C, 75% relative humidity, using a total exposure of at least 750 parts per million (by volume) for 12 hours (9,000 ppmv-hours). These tests also confirmed that the use of "test strips" containing surrogate spores is a valid way to verify the degree of decontamination achieved.

A decontamination plan should have the following elements:

- Pre-decontamination assessment to determine both "hot spots" and spatial distribution of organisms.
- Placement of test strips with the appropriate organisms in locations testing positive in pre-assessment phase.
- Locate test strips in areas (surfaces) where human contact is likely (i.e., desk surfaces) and where resuspension is possible (i.e., corridors, office entries).

BOX 10-2
Quoted from the Executive Summary of the EPA Sponsored Report "Analysis of Chlorine Dioxide Remediation of Washington, DC *Bacillus anthracis* Contamination,"
(Schaudies and Robinson, 2003)

This report provides a scientific analysis of chlorine dioxide gas testing and remediation efforts conducted or sponsored by the US Environmental Protection Agency (USEPA) in the Washington, DC, area in response to the anthrax attacks in October 2001. Commissioned by the USEPA Region III during the response phase to these attacks, this report summarizes and evaluates the available data from tests conducted by USEPA at a trailer test facility at the USPS Brentwood Processing and Distribution Center (hereafter referred to as the Brentwood PandDC), from the fumigation of the Daschle suite and part of the heating, ventilation, and air conditioning (HVAC) system of the Hart Senate Office Building (HSOB), from additional USEPA trailer tests in Beltsville, Maryland, and from USEPA-sponsored tests at the U.S. Army Dugway Proving Ground, Utah. Finally, this report offers key findings derived from all of these data concerning the effectiveness of chlorine dioxide gas for inactivating *Bacillus anthracis* spores under laboratory and field conditions.

The introduction of *B. anthracis* spores into the US Mail distribution system in the fall of 2001 presented a host of challenges to many government and civilian institutions. Envelopes containing approximately one to two grams of dry, weaponized *B. anthracis* spores resulted in contamination of multiple buildings in the Capitol Hill area. Levels of contamination ranged from 'just detectable' levels to visible powder on the floor in Senator Daschle's suite. The facts that 1 gram contains as many as 10^{12} spores and an infective inhaled dose may range from less than 10 spores to tens of thousands of spores presented some unique challenges for the cleanup operations.

The USEPA assumed overall responsibility for the remediation of buildings and artifacts within the Capitol Hill region. Localized small-scale remediation efforts were performed by high efficiency particulate air (HEPA) vacuuming, decontamination foam, and chlorine dioxide dissolved in water. Large-scale remediation was conducted by fumigating with chlorine dioxide gas in specific locations in the HSOB. This effort represented the first time chlorine dioxide gas was used for the destruction of *B. anthracis* spores outside of a laboratory and for decontamination on this scale.

Chlorine dioxide gas was selected for fumigation of the Daschle suite and a section of the HVAC system in the HSOB after careful consideration of several gaseous or vaporized alternative chemicals, including paraformaldehyde (heated into formaldehyde gas), ozone, ethylene oxide, and hydrogen peroxide vapor. While these alternative chemical decontaminants were all known to have potential effectiveness against *B. anthracis* spores, an interagency committee of advisors selected chlorine dioxide gas based on an objective evaluation using specific criteria that are described in paragraph 2.1.4.

Prior to the remediation of the HSOB, USEPA conducted a series of fumigations with chlorine dioxide gas in a trailer located at the Brentwood PDandC, which has been subsequently renamed the "Joseph Curseen-Thomas Morris PandDC."

The purpose of this testing was to determine the most effective combination of gas concentration, temperature, relative humidity, and contact time for fumigation of the HSOB Daschle suite and HVAC system. After the building remediation efforts were completed, USEPA conducted additional tests in a trailer at Beltsville, Maryland, and funded another study at the U.S. Army Dugway Proving Ground, Utah, on the efficacy of chlorine dioxide gas on live *B. anthracis* and several surrogate Bacillus species.

This report provides a scientific analysis of the results of all of the tests that were conducted or sponsored by USEPA to determine the most effective conditions for using chlorine dioxide gas to inactivate *B. anthracis* spores.

Finally, the authors wish to note that the historic, successful remediation of the HSOB is a tribute to the professionalism, dedication and hard efforts of all of the members of the remediation team led by the Capitol Police Board (CPB), the USEPA, Department of Defense, other federal agencies, and the Incident Commander, along with many local government fire and rescue teams.

Key Findings

1. Chlorine dioxide is an effective agent for the destruction of bacterial spores both as a gas and when dissolved in water. The data generated by the USEPA team from the use of chlorine dioxide gas at the HSOB and in separate tests provide strong evidence for the sporicidal effects of the oxidizer. The results obtained are supported by literature values determined in laboratory settings.
2. Initial testing with chlorine dioxide gas in a remediation test trailer at the Brentwood PandDC was crucial for the identification of successful operational parameters. These tests set the minimum levels for temperature, relative humidity, gas concentration, time of exposure, and indicator organisms to achieve the desired level of killing efficiency (see Key Finding 9 for details).
3. Insufficient time was allowed to train the personnel handling the spore strips. This training includes both the physical handling (placement, labeling, collection) as well as the subsequent laboratory culture analysis.
4. There was no confirmation of the type of organism cultured in positive spore strip samples taken during HSOB remediation. Therefore, one cannot conclude that the growth from indicator spore strips was from the indicator organism or a contaminant. Later analyses of cultured organisms from positive cultures from the Beltsville test trailer demonstrated that the organism contained in the spore strip culture frequently was not the original organism cultured, indicating a secondary source of contamination.
5. Inconsistent Steri-chart results confounded analysis within the offices of the HSOB. Approximately one-third of the Steri-chart series demonstrated positive growth at one level, negative growth at the next higher level, followed by positive growth at higher levels. These results were consistent with irregularities on the spore strip formulations.
6. Ineffective communications with the analytical laboratory resulted in the first 2 days of culture testing for spore strips, containing the test organism *Bacillus stearothermophilis*, being conducted at 37°C rather than at 60°C, the optimal temperature for this organism. This error, combined with the fact that positive cultures

(continued)

BOX 10-2 Continued

were not characterized, puts the additional information provided by this organism in question.

7. There was no consistent correlation between efficiency of kill and spatial placement of spore strips, for example, vertical surfaces were not remediated better or worse than horizontal surfaces. This was true for the HSOB as well as the trailer chambers.

8. Variability in the environmental conditions in the HVAC system, primarily the wide variation in relative humidity, complicated the analysis of the results, but the overall efficiency of both fumigations within the HVAC system was high.

9. Based on review of all of the data presented in this report, the minimum target gas concentration (C=750 parts per million [ppm]) and total contact time (CT) (T=12 hours) for a total CT of 9,000 ppmv-hrs appear to be just as important as the minimum temperature (greater then 75°F) and relative humidity (75%) to assure that chlorine dioxide kills bacterial spores.

Independent experimentation conducted at the West Desert Test Center at U.S. Army Dugway Proving Ground, which was funded by USEPA, indicates that relative humidity is a critical factor in chlorine dioxide remediation of *B. anthracis* spores. In addition, these tests were conducted on live *B. anthracis* as well as other surrogate spores on glass and paper. The results, presented in Appendix 1, provide further evidence that the conditions utilized for fumigation operations at the HSOB were effective against *B. anthracis* spores.

10. Use of spore strips and Steri-charts to measure the effectiveness of the use of chlorine gas to fumigate the Daschle suite and to fumigate a portion of the HVAC system indicated that those fumigations were not completely successful in reaching the target level of kill efficiency (10^6 reduction in spores) in all spore strips. However, the use of liquid chlorine dioxide to treat locations where spore strips were positive, and subsequent clearance sampling conducted in those locations and throughout the entire HSOB demonstrated no growth on all environmental samples. On that basis, the overall remediation was declared to be successful and the HSOB was cleared for re-opening.

- Select test strips with sufficient detection limits to quantify a minimum of 1×10^6 logs kill effectiveness.
- Topical decontamination and cleaning of areas known to be the primary site of heavy contamination or secondary accumulation sites, such as ventilation ducts, filters, and computer screens.
- Post-decontamination, the building should be reassessed to determine if primary agent is still present. Surface wipe sampling and/or vacuum sampling should target previously determined hot spots or areas of accumulation. Aggressive sampling might be considered prior to clearing the building for occupancy. Aggressive sampling might include mixing fans and mechanical agitation of upholstered/carpeted surfaces.

Significant improvements have been made in building remediation technologies since the decontamination of the Hart Senate Office Building. One clear example of the progress is the successful remediation of the American Media Incorporated building in Boca Raton, Florida, in July 2004. Below is a summary of laboratory validation of those operational events (Box 10-3).

BOX 10-3
Validation of *Bacillus anthracis* Remediation at the America Media Inc. Headquarters

The building that housed American Media Inc. headquarters in 2001, located at 5401 Broken Sound Blvd. in Boca Raton, Florida, was fumigated on July 11th, 2004 with chlorine dioxide gas in order to destroy the remaining *Bacillus anthracis* spores. The building was under operational control of BioOne Corporation for the entire remediation process. Extensive surface sampling with microbial culture indicated that the building had extensive contamination with some bacterial colony counts following analysis reported as "too numerous to count." During fumigation operations temperature, relative humidity (RH) and ClO_2 levels were co-monitored at 27 locations in the facility. Target temperature of 75 °F was maintained throughout all locations. RH of 75% was established prior to fumigation but was not maintained during the process; however, no locations fell below 65% RH. The minimum acceptable CT values were 9,000 ppm_V-hours; this value was exceeded at all 27 locations. The building achieved an average cumulative CT of 13,775 ppm_V-hours with individual locations ranging from 12,617 to 15,764 ppm_V-hours.

The building was functionally separated into 162 separate 100 sq ft grids for the biological indicator (BI) placement. Two thousand (2000) biological indicator spore strips located throughout the facility and exposed during fumigation showed a 100 percent kill rate.

BI Sampling Program Components

Program	BI Sample Type	Test Organism	Sample Number
	Single 10^6 spore strips	*B. atrophaeus*	810
Random Stratified	Duplicate 10^6 strips	*B. atrophaeus*	162
	Steri-charts (10^4 to 10^8)	*B. atrophaeus*	162
Focused	Single 10^6 spore strips	*B. atrophaeus*	137
ClO_2 Saturation	Single 10^6 spore strips	*B. atrophaeus*	81

The culture results for all of the 2000 spore strips are presented in the table below. None of the indicator strips were culture positive. All of the negative control strips were culture negative and all of the positive culture strips were culture positive.

(continued)

BOX 10-3 Continued

BII Overall Building Spore Strip Results

Program	Negative	Negative%
Random Stratified (including duplicates)	972	100
Steri-charts	162 (810 Total Strips)	100
Focused	137	100
ClO_2 Saturation	81	100
Total	2000	100

In addition to spore strip samples, 952 surface samples were collected from every area of the facility. All surface samples were analyzed by culture methodology at the New Jersey Department of Health and Senior Services State Laboratory in Trenton, New Jersey and found to be negative for *B. anthracis* growth. Following completion of surface sampling, aggressive air samples were collected at focused building locations using three sample methodologies; Dry Filter Units, High Volume Samplers, and Anderson Cascade Impaction Samplers. The focused air samples were all found to be negative for *B. anthracis* growth at the New Jersey State Laboratory. Following completion of focused air sampling; building-wide stratified aggressive air sampling was conducted utilizing Dry Filter Units positioned such that the intakes were located within the ceiling plenums directly in front of the air handler return ducts that serviced each building zone. Air volumes equivalent to 55 percent of total building volume were sampled during this event. All stratified air samples were found to be negative for *B. anthracis* growth at the New Jersey State Laboratory. Thus, the "no growth" standard for all environmental samples was achieved as a result of the fumigation.

FINDINGS AND RECOMMENDATIONS

Finding 10-1

Paraformaldehyde gas was the preferred decontaminant for buildings at the U.S. Army facility in Fort Detrick, which was home of the U.S. Army Medical Research Institute for Infectious Diseases. EPA has ruled out the use of paraformaldehyde for cleanup after a bioterrorist attack because of concerns about the health effects of the gas.

Recommendation 10-1

The committee recommends that the National Cancer Institute lead an interagency task force to reevaluate the possible carcinogenic effects of paraformaldehyde.

Finding 10-2
ClO_2 has been used successfully for decontamination of several buildings: the Hart Senate Office Building, the Brentwood postal facility, and the American Media Inc., building.

Recommendation 10-2
For now, and given its successful application after the 2001 attacks, ClO_2 should be considered the standard for decontaminating buildings—pending further guidance and information from federal agencies. Research leading to the development of new methods and processes should be expected to demonstrate that any new methods have the potential to be at least as effective, safe, and cost-effective as ClO_2 for decontamination.

Finding 10-3
Adequate training of the decontamination team is essential for effective remediation and validation.

Recommendation 10-3
EPA and the CDC should establish standards for remediation and validation of contaminated buildings and for the training of remediation teams.

Finding 10-4
The federal sterilization standard of a 6-log kill—the reduction of the amount of live contaminant by six orders of magnitude—was applied in the Hart Senate Office Building remediation. However, given that 1 g of dried *B. anthracis* can contain up to 10^{12} spores, the current standard could leave a large number of viable organisms.

Recommendation 10-4
Current and emerging decontamination techniques should be thoroughly evaluated to ascertain the achievable efficiencies of kill.

REFERENCES

Barbeito, M.S. 2001. Feasibility to Decontaminate Facilities Contaminated With or Suspected of Being Contaminated with *Bacillus anthracis*. Testimony Before Committee on Science, U.S. House of Representatives, Washington, DC: November 8, 2001.

Barrett, J.A., W.M. Jackson, I.A. Baig, A.L. Coverstone, C.E. Harfield, R.D. Arcilesi, J. Butler, W. Burton, and C.W. Williams, Jr. 2002. Wide Area Decontamination: CB Decontamination Technologies, Equipment, and Projects. Final Report. Edgewood, Maryland: Chemical Warfare/ Chemical Biological Defense Information Analysis Center.

DuPont. 1998. DuPont Oxone Monopersulfate Compound Technical Information. [Online] Available at: www.dupont.com/oxone/techinfo/.

Eng, P. 2002. Zapping Anthrax Mail with Ozone. [Online] Available at: www.newmedicine.org/Zapping_anthrax.htm.

Haas, C.N. 2001. Decontamination Using Chlorine Dioxide. Testimony Before Committee on Science, U.S. House of Representatives, Washington, DC: November 8, 2001.

Haley, M.V., C.W. Kurnas, R.T. Checkai, S.D. Turley, M.A. Osborn, and D.T. Burton. 2004. Toxicity of hydrogen peroxide-based decontamination solution (Decon Green) in water and soil extracts. 24th Army Science Conference Proceeding: Orlando, Florida. [Online] Available at: www.asc2004.com/Manuscripts/sessionO/OS-12.pdf.

Hoskins, A. 2002. SDSU Researcher Gets National Science Foundation Grant to Study Ozone's Effectiveness Against Anthrax. [Online] Available at: http://advancement.sdsu.edu/marcomm/news/releases/spring2002/pr042402.html.

INEEL (Idaho National Engineering and Environmental Laboratory). 2002. Potato Technology May Help Move Mail. DOE News Desk. [Online] Available at: http://newsdesk.inel.gov/contextnews.cfm?ID=275.

LLNL (Lawrence Livermore National Laboratory). 2005. Biological Restoration Plan for Major International Airports. Livermore, California: Lawrence Livermore National Laboratory.

Modec, Inc. 2002. MDF-200—An Enhanced Formulation for Decontamination and Mitigation of CBW Agents and Biological Pathogens. [Online] Available at: http://www.deconsolutions.com/pdf_files/DF-200%20Performance%20Data%20-Live%20Agent.pdf.

Modec, Inc. 2005. Sandia Decon Formulations for Mitigation and Decontamination of Chemical and Biological Warfare Agents, Chemical Toxins, and Biological Pathogens. [Online] Available at: http://www.deconsolutions.com/pdf_Files/MDF-200%20Data%20Sheet.pdf.

O'Connor, L., B. Harper, and L. Larsen. 2001. A Comparison of Decontamination Technologies for Biological Agent on Selected Commercial Surface Materials—Summary Report. Aberdeen, Maryland: U.S. Army Soldier and Biological Chemical Command.

Raber, E. 2002. L-Gel decontaminates better than bleach. Science and Technology Review March 2002: 10-16. Also [Online] Available at: www.llnl.gov/str/March02/Raber.html.

Raber, E., A. Jin, K. Noonan, R.R. McGuire, and R.D. Kirvel. 2001. Decontamination issues for chemical and biological warfare agents: how clean is clean enough. International Journal of Environmental Research and Public Health 11(2): 128-148.

Schaudies, R.P. and D.A. Robinson. 2003. Analysis of Chlorine Dioxide Remediation of Washington, D.C. *Bacillus anthracis* Contamination. McLean, VA: Science Applications International Corporation.

USPS (United States Postal Service). 2002a. U.S. Postal Service Emergency Preparedness Plan for Protecting Employees and Postal Customers from Exposure to Biohazardous Materials and for Ensuring Mail Security Against Bioterror Attacks. Washington, DC: United States Postal Service. Also [Online] Available at: www.usps.com/news/2002/epp/emerprepplan.pdf.

USPS (United States Postal Service). 2002b. Appendix A-H of U.S. Postal Service Emergency Preparedness Plan for Protecting Employees and Postal Customers From Exposure to Biohazardous Materials and for Ensuring Mail Security Against Bioterror Attacks. Washington, D.C.: United States Postal Service. Also [Online] Available at: www.usps.com/news/2002/epp/emerprepplan_ap.pdf.

Wagner, G.W., R.J. O'Connor, J.L. Edwards, and C.A.S. Brevett. 2004. Degradation and decontamination of VX in concrete. 24th Army Science Conference Proceedings: Orlando, Florida. [Online] Available at: www.asc2004.com/Manuscripts/sessionO/OS-03.pdf.

Weis, C.P, A.J. Intrepido, A.K. Miller, P.G. Cowin, M.A. Durno, J.S. Gebhardt, and R. Bull. 2002. Secondary aerosolization of viable *Bacillus anthracis* spores in a contaminated US Senate Office. Journal of the American Medical Association 288(28): 2853-2858.

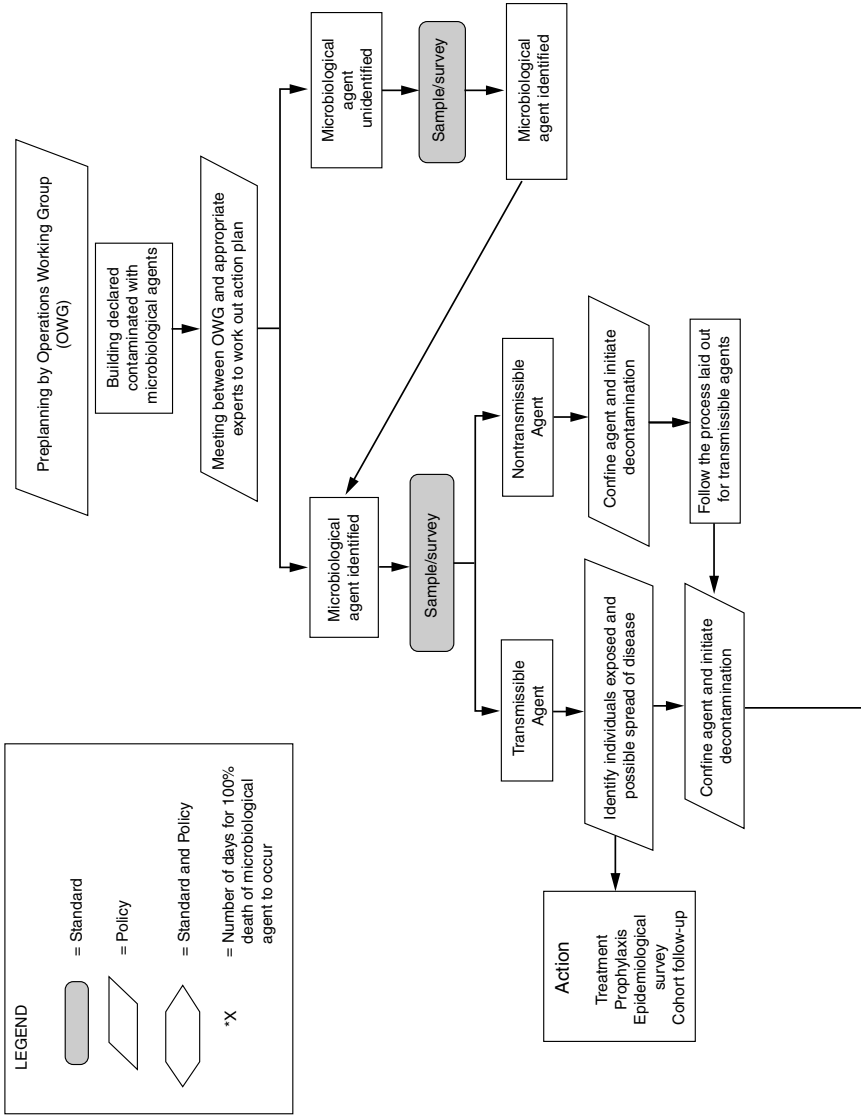
11

Safe Reoccupation of a Facility

Certifying that a building is safe for reoccupation is a complex process that involves decision making on several factors, including sampling procedures and decontamination methods. The process must consider quantitative risk assessments (Chapter 4) and the perspectives of stakeholders, users, and the public (Chapter 3). An official declaration that a building is safe for reoccupation is meaningless if the occupants and other stakeholders do not *perceive* it as safe. Without the involvement of the wider community, a technically perfect cleanup will be just that, and the building could remain unoccupied if public standards and criteria for assessing cleanup effectiveness differ from those accepted by the scientific community. Conversely, the expert appraisal of a building as not yet safe for occupation may be out of step with the ideas of building owners and users who are eager to reoccupy a structure.

In this chapter, the committee uses a flow chart to illustrate the critical steps in the decision-making process (Figure 11-1) for reopening a contaminated facility. The committee discussed the relevant standards and policies involved in decision making:

- A standard was used where the committee *recognized that a basis or principle to which everybody should adhere* should be developed to ensure national conformity of approach in the scientific and technical methods used and measurement of specific parameters upon which decisions about further action would be taken.
- A policy was used where the committee *recommended that a general course or principle of action or approach be adopted* throughout the country that



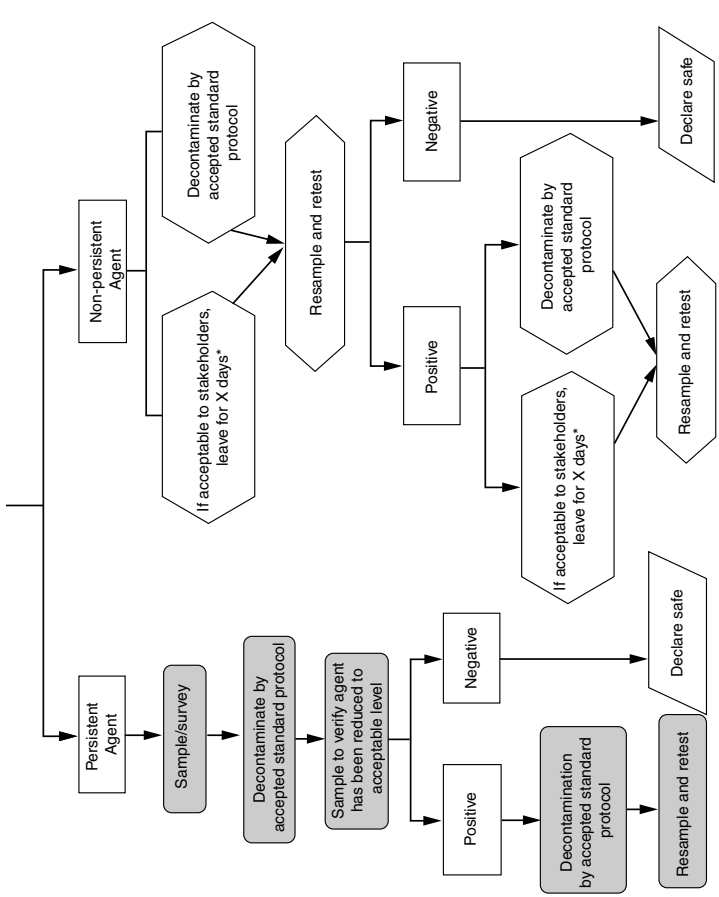


FIGURE 11-1 Flow chart illustrating the standard and policy guidance that could speed up and reduce cost of recovery from a bioterrorist attack. The flow chart is designed to address a biological weapon attack and has not considered combinations of biological and chemical or biological and radiological attacks.

would be applicable to all similar situations, regardless of how those situations might differ in detail.

Figure 11-1 ties together elements discussed in previous chapters of this report. This chapter underscores the value of planning in advance of a biological attack.

The cleanup response will depend on the biological agent and on its formulation. For instance, discovery of contamination, as evidenced by reports of infection, will lead to a response that depends first on the agent. If, like smallpox, the agent is transmissible, then the approach to decontamination will depend on whether the agent was transmitted as droplets from an infected individual or as a stable, lyophilized preparation. The latter will require intensive decontamination. If a liquid preparation is spilled, quick surface decontamination with liquid bleach of the affected area could suffice, pending subsequent sampling. Chronic exposure to *Bacillus anthracis* in wool mills led to relatively low rates of infection. Therefore, the physical properties of the particular agent preparation involved should be a major consideration with respect to the extent of decontamination.

PLANNING FOR BIOLOGICAL AGENT ATTACK

Decision making on the safe reoccupation of a building will be a simpler process if adequate contingency planning takes place *before* an attack. This section describes prudent steps that building managers should consider beforehand so that they will be prepared in the event of an act of bioterrorism. The planning should be designed to improve the timing and quality of decision making for safe reoccupation of a building. The application of these principles to a specific situation, an airport, is presented in Chapter 12.

Building owners, their facility managers, human resource personnel, and safety and health personnel (if present) should take primary responsibility for ensuring an emergency response plan is developed and practiced. Guidance and supporting assessment tools are available from authoritative sources (see Box 11-1). A well-reasoned process for confronting the immediate effects of a biological attack is likely to have a constructive effect on later efforts to return a building to use. Swift and effective containment of the biological agent in the initial response can limit the area of the physical environment that will require extensive decontamination. As Chapter 4 underscored, occupants and other stakeholders' confidence in the initial public health response after the 2001 attacks had long-term, positive consequences.

Owners of buildings should assume leadership for organizing a group concerned with preparedness; for simplicity, we refer to such a group as the Operations Working Group (OWG), which would likely have members who represent tenants, employees, and systems operation. Depending on the organization and the circumstances, security experts, union representatives, and other representatives of affected populations might also be included. In addition, experts in risk

Box 11-1
Online Resources for Building Managers:
Emergency Response Plans

Lawrence Berkeley National Laboratory's Indoor Environment Department (LBNLIED) provides guidance on how to assess the vulnerability of buildings and airports. Its website, http://securebuildings.lbl.gov, gives step-by-step advice for planning and the actions to take during an event (LBNLIED, 2004). The site gives access to training materials, dispersion models, and links to other reputable sources:

- Centers for Disease Control and Prevention Emergency Preparedness and Response, http://www.bt.cdc.gov/
- National Institute for Occupational Safety and Health, Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks, http://www.cdc.gov/niosh/bldvent/2002-139.html
- American Society of Heating, Refrigerating and Air-Conditioning Engineers, http://www.ashrae.org
- U.S. Army, Edgewood Chemical Biological Center, Homeland Defense, http://www.edgewood.army.mil/hld/index.htm
- U.S. Army Corps of Engineers Protective Design Center, http://buildingprotection.sbccom.army.mil/basic/airborne_hazards_report_download.htm

The National Response Plan, developed by the U.S. Department of Homeland Security, describes incident management approaches and how responsibilities would be distributed among federal agencies, state and local governments, and private citizens in a given set of scenarios. This plan is available online: http://www.dhs.gov/dhspublic/interapp/editorial/editorial_0566.xml

communication and health and safety would likely be useful additions to the group. The OWG would be charged with preparedness in the following areas:

- Building security and threat vulnerability assessment
- Building operations and systems and protocols for event response
- Occupant information and practice response
- Integration with local emergency and medical response services

The OWG has several purposes:

- Gather relevant information and documentation about building design and operation that can be used for initial containment and subsequent decontamination.

- Convene representatives of interested and affected parties to promote transparent decision making during the decontamination and reoccupation.
- Act as the point of contact for local emergency, public health, and medical responders.
- Communicate decisions and their rationale to building users and the public.

The OWG should begin by ensuring that current, accurate blueprints of the building or facility are available and accessible in an emergency. It should collect relevant information and initiate any studies necessary to gain an understanding of the building's air-handling system (Chapter 6). Knowledge of building design and operation will help the group determine the distribution of contamination and therefore the extent of cleanup required. That, in turn, will expedite the process of cleaning up the building to declare it safe.

The OWG should plan a public information initiative to explain the contamination issue, including its plan for gathering a contact list of all people in the building at a time they might have been exposed to a contaminant. The group also should communicate to building users *in advance of* any contamination event how decontamination would be organized in the event of an act of terrorism. A useful resource on this topic is the 1989 National Research Council Report *Improving Risk Communication*.

Decisions about decontamination and subsequent reoccupation should be made based on the best available scientific and technical information and should consider stakeholders' concerns. The critical assets of the OWG would be its firsthand understanding and experience with the facility in question and its grasp of local stakeholder concerns. The group might not, however, have the breadth of scientific and technical expertise appropriate to environmental sampling and decontamination challenges. It is not feasible for every building, organization, or institution to have a risk analysis specialist, an expert in biological weapons their effects, an expert in risk communication, an expert in public health, and scientists familiar with the latest sampling and decontamination technologies. Therefore, a more coordinated solution is needed so that the basics can be prepared by those experts.

The coordinated solution would distill lessons from previous cleanup efforts (for example, asbestos sampling and remediation and the cases presented in Chapters 2 and 3) and it would have the latest information on detection, sampling, and decontamination of biological weapons. That relevant information would be collected by those with access to the appropriate government agencies and it would include data on different potential approaches to detection and sampling (Chapter 8). The experts should thoroughly understand how inappropriate sampling techniques can result in false positives that lead to unnecessary cleanup efforts, or false negatives that can give the impression that a facility is cleaner (and therefore safer) than it actually is. An effective sampling protocol will increase confidence in the sampling data. Likewise, appropriate decontami-

nation methods should be used for each specific agent (Chapter 9). Effective sampling and decontamination will increase confidence in the cleanup process, which in turn will increase public confidence in the declaration of a building as safe. The group of experts should meet often to keep abreast of developing technologies and communicate that information to the relevant stakeholders. The outcome of the expert meeting would be a coordinated solution that is a one-stop location for information on cleanup.

The role of communicating the information is crucial and it will be important to ensure efficient, effective distribution of information in the event of an attack. The relevant agencies might prepare a series of documents or consider running a formal training program in various locations around the country. With a comprehensive understanding of the information, the local group can evaluate how it might need modification to account for specific circumstances, including the best ways to educate, inform, and involve local stakeholders.

The expert body also would need to be available to work with the OWG for the affected facility in the event of an incident. The two groups should collectively possess the breadth of technical expertise and localized facility knowledge so that affected people would be confident that decisions are based on the best scientific and technical information and that the concerns of all relevant stakeholders are considered. Planning, as described above, will facilitate decision making and allow quick response in the event of an attack. The biological attack response plan should be communicated to all stakeholders.

While the creation of a coordinated solution is pending, the OWG should identify the medical, public health, and law enforcement officials who should be notified in the event of an attack and compile contact information for the appropriate government agencies (the Centers for Disease Control and Prevention, the Environmental Protection Agency). Table 11-1 summarizes the actions and research that should be undertaken by different entities to hasten recovery from a biological attack.

BUILDING DECLARED CONTAMINATED

In the event of a bioterrorism attack, the OWG should call upon the expert group immediately. An attack could be overt or covert, and in the case of an overt attack, the perpetrator might announce the agent used as a way to increase the public anxiety. Such an announcement would provide the expert group with a starting point for assessing the nature and extent of contamination. The expert group would work with the OWG to begin sampling and surveying immediately, using the procedures outlined in the planning document. In the case of a covert attack, more extensive sampling and surveying, possibly combined with epidemiological investigations, could be necessary before the scope of the problem becomes clear (Chapter 5).

Table 11-1 Anticipating Acts of Bioterrorism

Actors	Immediate Action	Short-Term Plan	Long-Term Plan
Researchers	• Review, assess existing dose–response, sampling data; apply data to quantitative microbial risk assessment; identify additional information needed to increase confidence in the approach • Analyze dose–response data for biological agents by nonthreshold dose-response models • Reevaluate possible carcinogenic effects of paraformaldehyde • Evaluate current, emerging decontamination techniques to ascertain efficiency	• Additional research on dose–response data for biological agents • Evaluate existing environmental monitoring systems and syndromic surveillance systems for ability to provide information needed to detect and limit the spread of biological weapons • Conduct targeted research to assess dose–response data, suitability for extrapolation between species • Assess efficiency of sampling collection, analysis procedures for each biological threat substance	• Develop system to inexpensively identify, characterize biological threat agents • Develop in vitro techniques for dose-response information • Develop methods, technologies for decontamination

Federal government	• Distill lessons from previous contamination (asbestos, *B. anthracis*) • Expand National Response Plan to provide more scientific and technical information on biological weapons	• Assemble expert group to assist building owners, mangers in a bioterrorism attack	• Devise mechanism to keep all relevant actors abreast of developments in surveillance, sampling, decontamination • Iteratively revise decontamination standards, policies
Building owners, managers	• Convene Operations Working Groups	• Understand heating, ventilation, air-conditioning systems • Develop contingency plan	
Operations Working Groups	• Identify medical, public health, law enforcement officials for notification in the event of a bioterrorism attack	• Education • Devise mechanisms for receiving information updates	• Update information periodically • Develop risk communication strategy

Once the agent is identified, the initial decisions about decontamination will be made based on whether the agent persists in the environment, thus representing a continuing hazard to users of the space. The archetype agent is a spore of *B. anthracis*, and so in its deliberations the committee often referred to one phrase "tending to the *B. anthracis* archetype" to describe any agent that persists in the environment for longer than a few days. Although a nonpersistent organism will perish with time, some decontamination of the building could nonetheless be required. Unlike chemical and radiological contamination, biological contamination does not have a defined half-life. Genetic variations, physical alterations of the preparation, and environmental factors can increase or decrease the ability of a microorganism to survive for a significant period.

A second characteristic to consider is the extent to which the disease caused by the agent is transmissible from person to person. From a public health perspective, a transmissible agent with low persistence in the environment would represent a higher-order hazard to the community than would a nontransmissible agent. Each infected individual could spread the disease, potentially jeopardizing the community at large long after the original agent source is contained or removed. Public health officials would need to work in the community to identify people who might have been exposed and in need of treatment and those who might have spread the disease to others. The transmissibility of an agent does not affect decisions about decontamination and declaration of a building being safe, because the goal of decontamination is to ensure that the risk of being infected by the agent is minimal. Hence, building owners and managers should plan to decontaminate the facility until no organisms are found, regardless of the organisms' transmissibility.

An initial determination must answer two questions: Does the agent fit the *B. anthracis* archetype for stability, and is it transmissible between humans? In terms of the complexity of response and recovery, the worst-case scenario would be a persistent transmissible agent and the best-case scenario would be a nonpersistent, nontransmissible agent. Contamination with a transmissible persistent

BOX 11-2
Decision Milestones for Declaring a Building Safe for Return

- Does the agent fit the *B. anthracis* archetype for environmental persistence?
- Is the agent transmissible from person to person?
- What is the extent of the agent's spread throughout the facility and "satellites"?
- What is the most effective decontamination technology?
- Is there any residual contamination?
- Is the building safe for reoccupation?

agent would require extensive risk communication, careful epidemiological monitoring, and methodical decontamination. A persistent agent also poses another risk to the wider community through cross-contamination via fomites (inanimate objects that can carry disease-causing organisms), such as clothing and shoes.

Once the persistence and transmissibility of the agent are confirmed, the focus should shift to sampling and surveying, so that the extent of contamination can be estimated. Based on the sampling data, which reflect the potential spread of the agent in the building (Chapter 6), and the persistence and transmissibility of the organism, the expert group and the OWG would then determine the extent of decontamination required. Appropriate methods should be employed for the specific agent involved in the incident (Chapter 8). An evaluation of the efficacy of decontamination approaches for different agents is beyond the charge given to this committee. After decontamination, the building should be sampled and surveyed again for residual contamination. The number of samples needed to ensure safety would depend on the "source term" (the initial amount of contaminant deposited), the detection limit and efficacy of the sampling method, and the size of the facility (Chapter 8). If samples are positive, the building would need to be decontaminated again. The number of positive samples after decontamination compared with the initial estimate of organisms present will provide an estimate of the effectiveness of the decontamination procedure.

After the decontamination, the expert group and the OWG will face the critical decision of determining whether the building is safe for reoccupation. Although post-decontamination testing might not reveal signs of live harmful biological agents, the building cannot be guaranteed 100% free of the agent, because proving the absence of an agent is impossible. Therefore, risk assessment is needed to provide information on the probability that residual organisms remain in the building and the likelihood that residual organisms would lead to the infection of a human occupant (Chapter 4). If a vaccine exists that might be offered to potential occupants, the risk assessment should be done two ways, considering vaccinated and unvaccinated people. Sound policy advice on safe reoccupation should be based on consideration of and balance among the following points.

- *What is the detection limit for the viable agent of concern? How efficient are the sampling techniques and protocols? How sensitive is the technology for detecting viable agents and how confident are we that the approach used is representative of the overall contamination situation?*

As discussed extensively in Chapter 9, a sampling protocol with a high detection limit and high efficiency increases the confidence that the results are representative of the overall contamination situation.

- *What is known about the dose–response relationship for the agent of concern?*

Unlike radiological and chemical contamination, there is no documented threshold dose below which microorganisms have been proved to have no effect.

Although the probability of small doses of microorganism causing an infection could be low, one inhaled or ingested microorganism could potentially multiply within the body and lead to illness (Chapter 7). Hence, zero risk of infection cannot be guaranteed even after the best decontamination effort. Similarly, because of the complex interactions between microorganisms and humans, and because of the wide variability within both populations, it is impossible to calculate a specific number that can be labeled as the infectious dose for a generalized situation. However, we can establish dose–response curves that reflect the best available information on reactions to various amounts of agent. Those curves can be used in risk assessment.

- *Is there an appropriate "background" concentration of the agent that has previously been found to be safe for buildings of the type under consideration?*

The concept of natural background might not be particularly useful for determining the safe presence of an organism after an attack. Although *B. anthracis* occurs naturally in soil, spores specifically prepared for use as weapons do not occur naturally in buildings. In addition, the virulence of formulated biological agents can differ from their natural forms, further decreasing the applicability of the concept of a background concentration (Chapter 2). Another consideration involves the variations in susceptibility found within the human population.

The decision that it is safe to reoccupy a facility hinges on the balance between detection limits and acceptable risk. Risk analysis informs us of the probability of having any residual organisms in the building and of those residual organisms causing an infection in a human occupant, based on the detection limit, sampling efficiency, and dose–response data (Chapter 4). Stakeholders, building managers, and decision makers would need to work together to identify acceptable risk. If the risks are below that threshold, in the opinion of the expert group and the OWG, then the building can be declared safe for reoccupation. However, if the risks cannot be determined with confidence—because of high uncertainties associated with sampling or decontamination methods—the two groups could determine that the best choice would be to proceed with further decontamination to increase the probability of the building's safety for public use.

FINDINGS AND RECOMMENDATIONS

Finding 11-1

Effective response to and recovery from a biological attack requires expertise and input from scientists, public health experts, building engineers, and stakeholders. The response and recovery could be expedited substantially with adequate planning that involves the appropriate scientific expertise and all stakeholders. Although building owners and managers could begin the preplanning that involves the building structure and operations, technical and scientific planning involves expertise that is scattered across government agencies.

Recommendation 11-1

Owners and managers of high-value facilities should start planning now. A prompt, well-organized response will be needed to minimize the time a facility is out of commission. The committee recommends that the National Response Plan (specifically its Biological Incident Annex) or some other suitable federal document be expanded to provide more scientific and technical information on biological weapons, decontamination, sampling and surveying, epidemiology, and forensics. The document should describe how a team charged with collecting pertinent information for response to and recovery from a biological attack would operate in the context of a contamination event, which agencies would be responsible for which responsibilities, and who would be responsible for convening the members. The committee recognizes that the formation of such a team might take time and therefore outlines the following immediate, short-term, and long-term goals for building managers and the government to consider:

- *Immediate goal*. Building managers and owners should convene Operations Working Groups that include all relevant stakeholders to devise a response and recovery plan in the event of a biological attack. Because the group would not have all the necessary scientific and technical expertise, the Operations Working Groups should identify the appropriate government agencies and officials to contact in the event of an attack.
- *Short-term goal.* The federal government should identify a mechanism by which groups of experts would be assembled with the appropriate technical and scientific expertise to assist building owners and managers in the event of a biological attack. Those teams of experts would work with Operations Working Groups in the event of an attack to devise the best course of action for response and recovery. It might be modeled after the new central service recently announced by the United Kingdom's minister of the environment, which will "provide advice and guidance to responsible authorities during their contingency planning," among other functions (Department of Environment Food and Rural Affairs News Release of January 25, 2005).
- *Long-term goal.* The federal government should devise a mechanism by which it, and other relevant actors, would be kept abreast of developments and new technologies in surveillance, sampling, and decontamination and iteratively revise standards and policies for decontamination. That mechanism should ensure that updates would get to building managers and owners.

REFERENCES

LBNLIED (Lawrence Berkeley National Laboratory Indoor Environment Department). 2004. Advice for safeguarding buildings against chemical or biological attack. [Online] Available at: http://securebuildings.lbl.gov (accessed May 2, 2005).

NRC (National Research Council). 1989. Improving Risk Communication. Washington, DC: National Academy Press.

12

Harmful Biological Agents in a Public Facility: The Airport Scenario

Although all commercial airports have the same basic functions, they vary widely in design and management across the United States—and even more so throughout the world. If we limit our attention to the larger U.S. airports—those that seem of greatest concern in contemplating the consequences of an act of bioterrorism—there are some general characteristics we can list. Modern airports are complex places, resembling small cities in many respects. They often have dozens of buildings, including passenger and freight terminals and a host of maintenance, operational, and support facilities that include extensive areas for fuel storage.

Those "small cities" are often populated by tens of thousands of people: the travelers, the family and friends who might accompany them, the shippers who convey air freight to and from the facility, and also the employees. Airports in the United States accommodate more than 650 million passengers each year, and the largest—those in Atlanta, Georgia, and Chicago, Illinois—handle over 60 million annually. Airport employee populations can be counted in the thousands, and sometimes in the tens of thousands. The number varies, depending on the size of the airport and on the number of aviation-related facilities. Some major airports in the United States occupy as little as 600 acres; others cover more than 10,000 acres. Often, there also is major commercial and residential development crowding nearby, and at the smaller facilities, surrounding neighborhoods are part of an "airport city," a fact that is important for the technical and the social dimensions of dealing with an act of bioterrorism.

Airport passenger terminals include two general kinds of space—public space, routinely used by the traveling public, and support space, which houses

baggage processing, mechanical rooms, offices, storage, and a host of other activities. Although the baggage-handling spaces are not usually partitioned, other support spaces tend to be subdivided into relatively small rooms.

Although it is not outside the realm of possibility that a biological attack could be launched against any element of an airport to disrupt the overall operation, the passenger terminal would seem to be the most likely target. That terminal usually would be a large single building or complex of buildings that can range in size from several hundred thousand square feet to several million square feet. When the terminal consists of several buildings, they often are connected to facilitate easy movement of passengers and employees. The result is that air also mixes and spreads easily within the facility, and biological contaminants could migrate easily as well. Airport terminals are tied into the full range of utilities needed to serve large modern buildings. Often the utilities are linked to airport-wide plants by tunnels that are large enough to accommodate foot traffic by maintenance workers and, occasionally, by small vehicles. Another key functional element of all major airports is ground transportation for passengers, including public transit systems, car rental agencies, and facilities for privately owned vehicles. Sometimes these services are tied to enclosed or semi-enclosed spaces that also connect to passenger terminals.

All of the terminal spaces described above are served by heating ventilation, and air-conditioning (HVAC) systems that are similar to those in other large commercial buildings. There are greatly varying levels of sophistication and automation in airport HVAC control systems, largely as a function of the system's age. Although all move air into zones throughout the building to maintain appropriate temperature and humidity, the degree to which air flow can be rapidly modified or halted varies widely. HVAC systems are, of course, a major factor in any attack that would seek to release a biological agent into an airport terminal and therefore a major factor in the contamination that must later be remediated.

Few generalizations can be made about the interior materials in airport passenger terminals. Most have hard surfaces for floors and walls to facilitate maintenance and longevity, but some have softer materials (like carpeted floors) despite the need for frequent replacement. Such site-specific particulars as surface materials will have a major influence on decontamination after a biological attack.

Another consideration for decisions related to decontamination after a biological attack is that at any given time some aircraft generally are parked at a terminal. Those planes often are attached to the building by loading bridges, which in many respects render the aircraft an integrated element of the terminal building. Similarly, rail systems sometimes run through or are attached to airport buildings. Thus, contamination could extend to docked aircraft and rail systems, and possibly to other locations served by these aircraft or rail systems. The potential for contamination of docked aircraft and rail systems would be influenced by several factors, such as the method used at a particular gate for provid-

ing HVAC to a parked aircraft. Sometimes the aircraft's on-board systems are used, but there is a range of other means—even including HVAC supplied from the central plant that serves the terminal building. The connections between a terminal, aircraft on the airside and trains on the landside, increase the complexity of decontamination at the terminal in the event of a biological attack.

The number of people in an airport terminal at a given time depends on the schedule of airline flights. At some airports the pace of flight activity is relatively even throughout the operating day, so that the terminal's population remains steady as well. For a hub airport, the pace is set by the rhythm of the connecting banks of flights, and populations can vary widely throughout the operating day.

PLANNING CAN MAKE A MAJOR DIFFERENCE

Transportation agencies—airports in particular—are experienced in planning measures to prevent various forms of attack, including biological attack. Those plans, which include steps such as securing building air intakes, should continue to be a high priority, both in existing and in new facilities. The same agencies for many years also have recognized the benefits of planning for an emergency response to an attack. Airports routinely prepare, maintain, and periodically exercise emergency manuals, which set out the steps in considerable detail.

The unfortunate reality is that we could face the need to decontaminate a major transportation facility, and we would need to work through the complex technical and social decisions involved in such an effort, up to and including the decision to reopen the facility. The framework for the process is outlined in Chapter 11. It would seem prudent that the well-accepted practice of planning specific portions of a prevention and emergency response to a potential biological attack should be extended to include the decontamination and reopening of a given facility. Such preparation could substantially hasten the reopening of a facility that has been the target of such an attack.

The first, and perhaps most straightforward, step would be the identification of people—with specific contact information—who would assist in verifying the weapon used in an attack and the entities that appear to be the best candidates to assist in decontamination and sampling. In addition, specific contact information should be compiled for those local, state, and federal governmental agencies that could have a role in decontamination and reopening.

The next step would be the collection of site-specific engineering data, which would be essential for designing and validating the approach to sampling and decontamination. That information would include floor plans for the airport terminal, including equipment layouts, and an inventory of interior surface materials. Often the information already exists and it will be a matter of isolating it for ready access when needed. However, if the desired data do not already exist they might need to be assembled for this specific purpose. Examples include assess-

ments of the relationship of the various potentially contaminated spaces to other spaces or current, reliable data on the movement of air within the building as HVAC equipment operates. One reason gathering this information in advance is a concern is that airport terminal buildings often are built and modified in a series of contracts, usually administered by different entities. The airport owner might build the concourse, an airline might use a different contractor to construct a club in that concourse, and a concession operator might open restaurants or shops under yet another contract in the same concourse. Facilities might have been modified or renovated since the original construction documents were produced, and not all airports have effective control over maintaining current as-built drawings for all their tenant spaces. In that case, contract documents might not be conveniently located or organized to give a comprehensive and timely picture of current conditions in the terminal.

Although the normal operation of a building requires some continuing information on the subject, most likely, only new tests would yield the detail that would be useful for understanding the pattern of contamination that sampling a contaminated facility would suggest. In addition to gathering information on the movement of air within a facility, it would also be useful to sample the air within the facility to determine background concentrations of microorganisms. Sampling should be done over a range of occupancy and weather conditions as well as at modal connection points, such as rail stations if they are present. Even then, the sampling data would, at best, provide only a loose reference point for future comparison because of the sensitivity of air content and quality values to a host of factors that vary widely from day to day and even from hour to hour. Nonetheless, some prior reference points could provide valuable information for beginning decontamination with an intense focus on air content issues.

Another aspect of planning would involve contingency plans for maintaining the airport's service. Planning for the potential loss of capacity could minimize disruption to the transportation system. For a major connecting airport dominated by a principal carrier, that airline might be able to reroute a portion of its schedule through another airport to compensate for the connecting traffic capacity taken out of service because of decontamination efforts. At an origin-and-destination airport, the contaminated terminal space might represent the entire capacity of one or more carriers. In that case, planning could consider the possibilities for relocating flights from the affected areas to an unaffected terminal, if available, or to another regional airport. In either case, significant capacity replacement could be required for the duration of the decontamination effort.

An additional step deals with identifying the entities that should be represented in a group that would oversee the process of actual decontamination and reopening of an airport. That could be the most important step for achieving rapid decontamination and reoccupation. Ultimately, that group will be looked to for assurance that a once-contaminated facility is safe to reopen. In some ways, that step also could be the most difficult to accomplish. However, if the groundwork

is not done in advance, the formation of such a group under the intense stress, pressure, and publicity of an actual event will make any planning difficulties look small by comparison.

The makeup of such an Operations Working Group is discussed in Chapter 11. In an airport, that group should include knowledgeable technical people, those with onsite engineering skills; employee representatives, including those from unions, airlines, and other companies that do business in the facility; representatives of neighboring communities and of more distant communities that depend on air service through the facility (the "spokes" in a "hub and spoke" arrangement); and other parties whose views during and after the cleanup would be valuable and credible. That body should come together at the planning stage, and periodically thereafter, so it achieves a sense of mission and cohesion, and to the extent possible, so that its members would be able to work their way through the shock and horror of the overall subject. That way, if the group were faced with an actual event, those very human reactions might be mitigated.

The final step is the development of a framework for public communication. Anticipating the confusion that a biological attack would create—confusion that could well remain throughout the decontamination and reopening phases—it is highly desirable that a transparent and straightforward but disciplined communication process is worked out beforehand with the group assembled. Research done early in the planning process can provide valuable information about stakeholders, available communication channels, trust issues, perceptions of risk, and appropriate spokespersons who could help with the communication needed in the aftermath of an attack. Advance discussion of potential scenarios can be useful for increasing trust and could decrease problems that could arise from a lack of familiarity with the issues.

FINDINGS AND RECOMMENDATIONS

Finding 12-1
Airports, particularly passenger terminals at airports, are vulnerable to biological attacks, because of the high-profile nature of aviation and because of the densely populated, large, often interconnected interior spaces that such terminal facilities comprise. Aircraft often are connected to terminals so departing aircraft could spread a pathogen to distant points if a biological attack on the terminal were not immediately recognized. The same threat is also presented at airports served directly by urban transit systems—such as rail lines—that are connected to a passenger terminal.

Recommendation 12-1
To deal with the aftermath of a biological attack, airport operators should anticipate the need for access to diverse and highly specialized resources, including

information on control of air flow. Airport operators should assemble, adopt, and maintain detailed plans to identify, contact, and mobilize those resources. The plans and associated resources should be updated periodically, and they should be stored in locations that would be accessible in the case of an event.

Finding 12-2
Airport operators are experienced at preparing, adopting, and using specific procedures to cope with the immediate-response aspects of a broad range of emergencies. The same aggressive approach to planning could be usefully applied to the projected aftermath of a biological attack, including the decontamination and reopening sequences that such an attack would occasion. In the event of an actual biological attack, the availability of a soundly drawn plan derived from a comprehensive process would certainly hasten the reopening of a facility.

Recommendation 12-2
Plans should contain pertinent physical information on facilities, including floor plans, material characteristics, air circulation patterns, and air sampling data. The plans also should identify, and provide current contact information for, organizations and individuals who could be rapidly mobilized to identify the attacking agent and those who would be available to assist with the actual decontamination.

Finding 12-3
Acceptance of the decision to reoccupy a facility will be more successful if an Operations Working Group is formed before an event occurs, and if that group includes people with scientific, technical, and medical expertise and those whose daily lives would be affected by contamination of the airport.

Recommendation 12-3
Planning should identify the interested parties, form them into a working group, and have them interact regularly in anticipation of coming together to guide an actual recovery effort. That effort should be executed in a manner designed to maximize trust among the various participants and stakeholders.

Appendix A

Statement of Task

To address the issue of appropriate cleanup levels for decontamination of public transportation facilities (e.g., airports, subways) affected by exposure to harmful biological agents, the National Academies will convene an ad hoc committee of experts to conduct a study that will be designed to lay the technical foundations for the establishment of standards and policies for biological decontamination. Elements of the study will include:

Infectious dose: Because differences among organism types may require fundamentally different approaches for decontamination and risk assessment, the committee will evaluate the current understanding of infectious dose for key biowarfare-related biologicals (e.g., *Bacillus anthracis*). This will include relevant representative organisms among the infectious/noncontagious and infectious/contagious gram-positive and gram-negative bacteria and viral pathogen classes. Given that some biological agents degrade rapidly without treatment so that decontamination is not necessary, the committee will first identify members of each key group that require decontamination, and then select one or two representatives of each key group for in-depth assessment. In addition to lethal pathogens, the committee may also consider pathogens that may typically be nonlethal, but whose virulence may result in the incapacitation of large numbers of people, thereby causing disruption and panic. The 2001 anthrax attacks called the state of knowledge on infectious dose for this organism into serious question. The committee will assess the validity and uncertainty associated with current knowledge of infectious doses and identify areas in which additional knowledge from research is required. The committee will first examine the existing dose–response models for each selected organism. It will then evaluate whether there is a threshold dose below which there is no impact (infectious dose zero, ID0). An

important part of this study is to understand existing natural environmental background levels for various microorganisms and their potential effect on the surrounding population. Individuals tolerate certain levels of microbial pathogens in the environment and these levels need to be taken into account in assessing risk. The committee will also determine the cleanup levels associated with a range of infectious doses (e.g., 1:1,000,000 to 1:10,000, or $ID10^{-6}$ to $ID10^{-4}$) and describe how these data could be used to assist in establishing acceptable measures of decontamination for selected organisms.

Quantitative risk assessment models: The committee will examine existing quantitative risk assessment models and evaluate whether these models can be adapted for purposes of assessing the safety of decontaminated public transportation facilities or whether new models need to be developed. In either case, the committee will develop the conceptual components of the four risk assessment steps (hazard identification, exposure assessment, dose–response assessment, and risk characterization) for the key organism types considered in the study. Hazard identification identifies aspects of the organisms (e.g., infectivity) and situations (e.g., form of biological hazard, such as fine aerosol) that represent threats to human health. Exposure assessment estimates the dose encountered considering the sources (including existing environmental background levels), spatial distribution of organisms, duration of exposure, and exposure pathways (ingestion, inhalation, and dermal exposure). Dose–response assessment uses available data to relate dose to adverse health response. Risk characterization combines exposure and dose–response assessment to quantify, for a defined population (considering, for example, age, sex, ethnicity, and overall health of population) the risks predicted to result from the exposure. The committee will test the models for relevant representative organisms to assess the potential risk associated with identified options for clean up levels.

Natural and residual contamination: An additional component for the committee to consider is the means of estimating the exposure level that could arise from residual contamination at various locations in a facility (e.g., inside air ducts or from equipment). The committee will comment on the role of the time factor for degradation in various environments (with and without treatment) to help determine decontamination approaches and requirements. The committee will evaluate various approaches (for example, monitoring schemes and performance evaluation targets) and describe how this information could be used to assist in determining safe levels of residual contamination. Relevant information on natural environmental backgrounds that individuals encounter with few or no health effects will also be included and evaluated here.

Past cleanup efforts: The committee will review the various efforts put into the cleanup of *B. anthracis* following the events of last year in order to more completely understand the implications of exposure and dose to infectivity and immunity. These reviews will look at both federal and private efforts, including the ongoing cleanup in Florida.

Appendix B

Presentations to the Committee

November 24-25, 2003

Dennis Imbro, Lawrence Livermore National Laboratory: Decontamination and Restoration of Major Transportation Facilities

Ellen Raber, Lawrence Livermore National Laboratory: How Clean Is Clean Enough? Recent Developments in Response to Threats Posed by Chemical and Biological Warfare Agents

Nina Marano, CDC: Responding to *Bacillus anthracis*-Related Bioterrorism

Mark Wheelis, University of California, Davis: History of Biological Weapons

Kenneth Martinez, CDC: Environmental Sampling During the Anthrax Outbreak Investigations

Dorothy Canter, EPA: Anthrax Cleanups: Addressing Residual Risk Issues

Laura Rose, CDC: Environmental Bioterrorism Research Activities

Robert Eckhaus, Edgewood Chemical Biological Center, U.S. Army: Capabilities in Support of How Clean Is Safe

January 28-29, 2004
Tom Day, United States Postal Service: Decision Making Process for Declaring Brentwood Postal Facility Safe for Use

David Franz, Midwest Research Institute: (1) Comments on What Type of Standards and Guidelines Are Needed to Determine "How Clean Is Safe?" and (2) Information About Anthrax, Smallpox, and Plague

C.J. Peters, University of Texas, Medical Branch at Galveston: Information About Anthrax, Smallpox, and Plague

Dick Spertzel, U.S. Army (retired): Issues of Weaponized Microbes

M. Louise M. Pitt, USAMRIID: Information About Dose–Response

Rick Batycky, Alkermes, Inc.: Information on Lung Physiology and Delivery of Microbes

Ray Mariella, Lawrence Livermore National Laboratory: Reliability of Detection

Calvin Chue, Johns Hopkins University: Mechanisms of Detection

Linda Stetzenbach, University of Nevada, Las Vegas: (1) Sampling Methods on Various Surfaces Using Simulant Organisms and (2) Natural Background

Richard Sextro, Lawrence Berkeley National Laboratory: Air Movement in Subways and Buildings and Reaerosolization of Microbes

Jeanine Prud'homme, New York City Department of Public Health: Information on Public Health

Brandolyn Thran, U.S. Army: Risk Assessment

Tony Cox, Cox Associates: Risk Assessment

March 29-31, 2004
Dean Wilkening, Stanford University: Human Effects Model for Inhalation Anthrax

Caron Chess, Rutgers University: Risk Communication

Kimothy Smith, Lawrence Livermore National Laboratory: Natural Background Levels of Anthrax

Terri Tanielian, RAND Corporation: Employee Decision-Making on Returning to Work at Brentwood and on Capitol Hill

John Eck and Laura Tankenson, NBC: Anthrax Incident at NBC

Peter Biggins, Dstl Chemical and Biological Sciences: Aerosols and Detection

July 20, 2004
E. Barry Skolnick: Surface-testing Issues in Bioagent Detection and Decontamination

October 13-14, 2004
John Mason and Karen Cavanagh, Sabre Technical Services, LLC: Decontamination and Sampling at AMI

Mike Shoemaker and Greg Knudson, Armed Forces Radiobiology Research Institute: Clearance Decisions After 2001 Attacks

Tyler Cymet and Shivang Joshi, Sinai Hospital of Baltimore: Long Lasting Health Effects of Exposure to *Bacillus anthracis*

Appendix C

All Findings and Recommendations

Finding 2-1
Naturally occurring infectious-disease hazards provide much information that is useful for biodefense consequence management planning, but weaponized biological agents could pose special threats that are distinct from those attributable to naturally occurring hazards, especially when it comes to decontamination.

Recommendation 2-1
Decontamination decisions and plans should consider the natural characteristics of a specific pathogen and the weaponization characteristics of that agent. Weaponized agents can vary in infectivity and virulence as a result of formulation, and the presence of a natural background of weaponized agents (such as weaponized *B. anthracis*) is unlikely in indoor public facilities. Given the uncertainties in the characteristics of the weaponized agents, it is impossible to establish acceptable thresholds below which exposure to such weaponized agents would pose zero risk.

Finding 3-1
Determining acceptable risk is a complex issue: Willingness to accept risk varies from person to person, from situation to situation, and from culture to culture. Managing risk also is complex: Different people have different ideas about how much responsibility the government or the owners and operators of public facilities and lands have to limit public exposure to risk. Those issues have been considered in many situations, and many policy-making lessons can be learned from events involving Superfund and the U.S. Department of Energy.

Recommendation 3-1
In contemplating how to respond to potential biological attacks, authorities should base their plans on lessons from the experiences of others who have dealt with decontamination issues in the broadest sense; they should not consider their charge a completely novel task. Decision making about a facility contaminated as the result of a biological attack should be mindful of the critical policy dimensions of the biological quality of the hazard, the public nature of the building, the public's perception of an attack, and the event's national security implications.

Finding 3-2
If safety-related standards and protocols are devised and implemented behind closed doors, without the consent or input of affected and interested parties, those standards are likely to be questioned or rejected outright. Lack of transparency for policy decisions that directly affect public health—even in the context of a proclaimed national security interest—can severely erode public confidence. The establishment of a formal planning procedure that involves relevant stakeholders before an event should expedite the response and confer legitimacy for decisions made during and after decontamination.

Recommendation 3-2
Representatives of affected parties should be involved in risk management decision making, and they should participate in the technical discussions needed to make decisions. Engaging the people whose well-being is most at stake helps ensure their greater confidence in the outcome of risk-based decisions. Those who provide the technical information should be independent experts who are free of conflicts of interest, so that they can give the highest priority to protecting public health. Stakeholder involvement in risk assessment and management provides valuable returns: local knowledge that can contribute to a more robust definition of the danger, greater public confidence in scientific tools that support public policy, and more widespread acceptance of the legitimacy of the results.

Finding 3-3
People and microorganisms cohabit the world; their interactions sometimes result in human disease. Nonetheless, in settings where people risk exposure to pathogens (laboratories, hospitals), biological safety policies can protect against human disease. Decontamination is not a standalone activity, but part of a larger set of controls over dangerous microorganisms and their potential health effects. The domestic institution that routinely dealt with weaponized pathogens—the U.S. Army Biological Warfare Laboratories—developed a comprehensive set of biological safety programs to control those pathogens. Protective measures ranged from preemptive vaccination to medical monitoring and treatment for inadvertent exposures.

Recommendation 3-3
Integrated protection for human health is the most prudent policy in the context of a facility contaminated as the result of a biological attack. After a facility has been decontaminated, some type of medical monitoring is critical to ensure confidence that a facility is safe, and the purpose and outcome of medical monitoring should be made transparent to affected parties. In the event of any incident in the future, a centralized and sustained effort should be organized to track the health of those exposed, or potentially exposed, to pathogens.

Finding 4-1
Acceptability is not a technical concept. It is a values concept. It is, therefore, best constructed through an analytical and deliberative process that involves key stakeholders in a potentially harmful situation. Without trust, acceptability is difficult to achieve. Effective leadership in dangerous situations is based on openness and honesty, even when bad news must be conveyed. Transparency in decision making can contribute substantially to ensuring the acceptability of risk. Panic is rare in disasters, and it is an unhelpful idea for explaining how people respond to frightening situations and information. After the 2001 anthrax attacks, decision makers sometimes relied on assumptions that later proved unfounded; their subsequent actions resulted in significant problems with communicating the degree of risk involved to the stakeholders.

Recommendation 4-1
Risk managers who face potential contamination should assume that the problem could be worse than they initially think. In remediation projects, the public should be seen as an asset, not a liability, and information should be made available widely. Indeed, the public should participate actively in decision making in the aftermath of an attack. Following the lead of previous work by the National Academies, the committee recommends that an analytical deliberative process be used to determine appropriate approaches for cleanup.

Finding 4-2
Relevant data from the sites contaminated in 2001 were not shared with all necessary parties, partly because of the differing goals and objectives of law enforcement and public health agencies. Lack of data sharing can compromise health in the aftermath of a biological attack.

Recommendation 4-2
Agencies and organizations entrusted with data relevant to public health should make every effort to share this information. Cooperation is the key to decreasing public anxiety, and agreements, such as the one signed by the New York City Department of Health and relevant law enforcement agencies, should be in place

to protect public health and safety by allowing the process of forensic evidence collection and decontamination to proceed unimpeded by one another.

Finding 5-1
The QMRA process, developed over the past 20 years, has been used to inform decision making about events involving microbial hazards that affect food safety, drinking-water quality, and the use of isolation rooms in hospitals.

Recommendation 5-1
A risk assessment approach should be adopted as one component of decision making for determining the adequacy of decontamination efforts after a release or suspected release of a biological contaminant.

Finding 5-2
Thorough risk analysis requires critical information about each variable. This information is weak for certain variables when one considers agents that might be used in a biological attack.

Recommendation 5-2
More dose–response and sampling source data are needed to inform a practical, as opposed to a theoretical, risk analysis for any given biological attack.

Finding 6-1
Detailed characterization (including screening for known threat agents, genetically modified and emerging threat organisms) of a suspected biological pathogen is required for proper analysis and to inform decision making.

Recommendation 6-1
Research should be conducted to develop a characterization system that can inexpensively identify, or approximately characterize, all potential threat agents including genetically modified and emerging threat agents.

Finding 6-2
Identifying and characterizing the properties of an organism (or organisms), and the amount and extent of its concentration at the time cleanup begins, are critical to making decisions about response options.

Recommendation 6-2
Characterizing the contaminating agent or agents should be done before selecting the approach for large-scale remediation. The remediation approach chosen should be one that can adequately destroy (or remove) the amount of agent present at the start of the procedure.

Finding 6-3
The earlier contamination is detected the easier it will be to restrict the area of contamination and the number of individuals who will be exposed. In the case of the 2001 anthrax letter mailings, the event first came to light through the observations of an astute physician. Different monitoring systems—environmental (e.g., Biowatch) and medical (e.g., syndromic surveillance) in nature—have since been put in place with the hope of obtaining the earliest possible indicator regarding the release of a biological agent.

Recommendation 6-3
Existing environmental monitoring systems and syndromic surveillance systems need to be evaluated for their abilities to provide information that can be used to detect and to limit the spread of biothreat agents in a cost effective manner. If those systems prove to be effective, they could be deployed in public facilities that may be likely targets for attacks.

Finding 7-1
Biological agents can spread beyond their point of initial release in air-handling systems, through the reaerosolization of contaminants from floors and other surfaces by foot traffic or air currents, and by adhesion to people or their clothing. Those factors can result in widespread dispersal of biological contaminants within a building and into transportation and transit vehicles, homes, and other sites.

Recommendation 7-1
An extensive survey should be done to determine the extent to which biological contamination has spread. (Further guidance on surveying and sampling can be found in Chapter 9.)

Finding 7-2
Indoor air-handling systems can redistribute biological agents by carrying airborne contaminants throughout buildings and outdoors. However, if appropriate actions are taken, air-handling systems also can be used to confine contaminants and reduce the effects of contamination.

Recommendation 7-2
Building operators should act now to gain a thorough understanding of how air flow occurs in their buildings under normal operating conditions. They also should examine the potential adverse or beneficial effects of a shutdown on the spread of airborne contaminants so that appropriate actions could be taken to minimize the dispersal of contaminants if the release of a biological agent is identified.

Finding 7-3
Architects, construction engineers, ventilation engineers, facility operators, and other professionals involved with building design, construction, and operation have an inadequate understanding of how the built environment affects occupants.

Recommendation 7-3
The professions related to the building industry and facility management should be better educated on the nature of their vulnerability to weaponized agents so they will be prepared to respond to an act of bioterrorism. Professional societies (such as the Building Owners & Managers Association, and the International Facility Management Association), state and federal agencies, and academic institutions should fund and participate in efforts to increase understanding of those issues through education and training.

Finding 8-1
The concept of a "threshold" below which no risk to a population exists for a microbial dose response is not supported by currently available data. Nonthreshold dose–response models present a more cautious approach that has been found appropriate for describing human response to a diversity of infectious agents via ingestion, inhalation, and other routes of exposure. Dose–response data for most of the pathogens of concern (biological agents) are incomplete or have not been critically analyzed in the open literature.

Recommendation 8-1
Available dose–response data for pathogens of concern should be analyzed by non-threshold dose–response models.

Finding 8-2
Because minimal publicly available data exist on which to base human dose–response relationships for the critical pathogens, animal data must be used. However, our understanding of interspecies extrapolation of dose–response relationships for infectious agents from animals to humans is low.

Recommendation 8-2
Targeted research to help inform decision making on extrapolation of dose–response data between species for the pathogens of concern should be conducted. That research might use several species of organisms or use animal and human tissues to reach conclusions that are relevant for human exposures. With the increasing difficulty of performing primate studies, it will become more important to develop in vitro techniques that can be used to develop dose–response information.

Finding 9-1
General Centers for Disease Control and Prevention (CDC) sampling guidance exists for *Bacillus anthracis* spores, but there is no official guidance for the collection of vegetative *B. anthracis*, plague bacteria, nor smallpox virions.

Recommendation 9-1
Sampling protocols must be appropriate to the threat. Sampling for *B. anthracis* spores should be done according to published guidance from CDC and the National Institute for Occupational Safety and Health. The CDC and the American Society for Microbiology should develop sampling and analysis guidelines for the other threat agents. Other agencies (such as the U.S. Environmental Protection Agency [EPA] and the FBI) that may be involved in sampling also should be consulted.

Finding 9-2
Surface sampling with dry wipes led to false negatives at the Wallingford postal facility and to inconlcusive results at the Brentwood postal facility.

Recommendation 9-2
Dry-wipe and dry-swab surface sampling should be abandoned in favor of wet-surface swipe techniques. HEPA vacuum surface sampling should be continued as complementary to surface swiping.

Finding 9-3
Different threat substances require different sampling protocols. The variety of collection approaches currently in use results in widely varying collection and extraction efficiencies, which hamper attempts to quantify the initial extent of contamination.

Recommendation 9-3
Sampling and analysis should be standardized. Research should assess the efficiency of collection and analysis for each type of biological agent. Unless the sampling efficiency is known, the amount of contaminant deposited cannot be estimated with confidence.

Finding 9-4
There is consensus within the federal government regarding the value of a general sampling plan to guide the use of various surface-, air-, and bulk-sampling methods.

Recommendation 9-4
The general sampling plan should be the result of the consensus of facility stakeholders; medical, public health, and environmental experts; decontamination tech-

nologists; laboratory analysts; and worker safety representatives. It should encompass three phases: (1) confirmation and contamination baseline, (2) assessment and characterization, and (3) decontamination effectiveness. Some sharing of expertise will be necessary for all groups to be well enough informed to come to consensus.

Finding 10-1
Paraformaldehyde gas was the preferred decontaminant for buildings at the U.S. Army facility in Fort Detrick, which was home of the U.S. Army Medical Research Institute for Infectious Diseases. EPA has ruled out the use of paraformaldehyde for cleanup after a bioterrorist attack because of concerns about the health effects of the gas.

Recommendation 10-1
The committee recommends that the National Cancer Institute lead an interagency task force to reevaluate the possible carcinogenic effects of paraformaldehyde.

Finding 10-2
ClO_2 has been used successfully for decontamination of several buildings: the Hart Senate Office Building, the Brentwood postal facility, and American Media Inc., building.

Recommendation 10-2
For now, and given its successful application after the 2001 attacks, ClO_2 should be considered the standard for decontaminating buildings—pending further guidance and information from federal agencies. Research leading to the development of new methods and processes should be expected to demonstrate that any new methods have the potential to be at least as effective, safe, and cost-effective as ClO_2 for decontamination.

Finding 10-3
Adequate training of the decontamination team is essential for effective remediation and validation.

Recommendation 10-3
EPA and the CDC should establish standards for remediation and validation of contaminated buildings and for the training of remediation teams.

Finding 10-4
The federal sterilization standard of a 6-log kill—the reduction of the amount of live contaminant by six orders of magnitude—was applied in the Hart Senate Office Building remediation. However, given that 1 g of dried *B. anthracis* can

contain up to 10^{12} spores, the current standard could leave a large number of viable organisms.

Recommendation 10-4
Current and emerging decontamination techniques should be thoroughly evaluated to ascertain the achievable efficiencies of kill.

Finding 11-1
Effective response to and recovery from a biological attack requires expertise and input from scientists, public health experts, building engineers, and stakeholders. The response and recovery could be expedited substantially with adequate planning that involves the appropriate scientific expertise and all stakeholders. Although building owners and managers could begin the preplanning that involves the building structure and operations, technical and scientific planning involves expertise that is scattered across government agencies.

Recommendation 11-1
Owners and managers of high-value facilities should start planning now. A prompt, well-organized response will be needed to minimize the time a facility is out of commission. The committee recommends that the National Response Plan (specifically its Biological Incident Annex) or some other suitable federal document be expanded to provide more scientific and technical information on biological weapons, decontamination, sampling and surveying, epidemiology, and forensics. The document should describe how a team charged with collecting pertinent information for response to and recovery from a biological attack would operate in the context of a contamination event, which agencies would be responsible for which responsibilities, and who would be responsible for convening the members. The committee recognizes that the formation of such a team might take time and therefore outlines the following immediate, short-term, and long-term goals for building managers and the government to consider:

- *Immediate goal*. Building managers and owners should convene Operations Working Groups that include all relevant stakeholders to devise a response and recovery plan in the event of a biological attack. Because the group would not have all the necessary scientific and technical expertise, the Operations Working Groups should identify the appropriate government agencies and officials to contact in the event of an attack.
- *Short-term goal.* The federal government should identify a mechanism by which groups of experts would be assembled with the appropriate technical and scientific expertise to assist building owners and managers in the event of a biological attack. Those teams of experts would work with Operations Working Groups in the event of an attack to devise the best course of action for response and recovery. It might be modeled after the new central service recently an-

nounced by the United Kingdom's minister of the environment, which will "provide advice and guidance to responsible authorities during their contingency planning," among other functions (Department of Environment Food and Rural Affairs News Release of January 25, 2005).

- *Long-term goal.* The federal government should devise a mechanism by which it, and other relevant actors, would be kept abreast of developments and new technologies in surveillance, sampling, and decontamination and iteratively revise standards and policies for decontamination. That mechanism should ensure that updates would get to building managers and owners.

Finding 12-1
Airports, particularly passenger terminals at airports, are vulnerable to biological attacks, because of the high-profile nature of aviation and because of the densely populated, large, often interconnected interior spaces that such terminal facilities comprise. Aircraft often are connected to terminals so departing aircraft could spread a pathogen to distant points if a biological attack on the terminal were not immediately recognized. The same threat is also presented at airports served directly by urban transit systems—such as rail lines— that are connected to a passenger terminal.

Recommendation 12-1
To deal with the aftermath of a biological attack, airport operators should anticipate the need for access to diverse and highly specialized resources, including information on control of air flow. Airport operators should assemble, adopt, and maintain detailed plans to identify, contact, and mobilize those resources. The plans and associated resources should be updated periodically, and they should be stored in locations that would be accessible in the case of an event.

Finding 12-2
Airport operators are experienced at preparing, adopting, and using specific procedures to cope with the immediate-response aspects of a broad range of emergencies. The same aggressive approach to planning could be usefully applied to the projected aftermath of a biological attack, including the decontamination and reopening sequences that such an attack would occasion. In the event of an actual biological attack, the availability of a soundly drawn plan derived from a comprehensive process would certainly hasten the reopening of a facility.

Recommendation 12-2
Plans should contain pertinent physical information on facilities, including floor plans, material characteristics, air circulation patterns, and air sampling data. The plans also should identify, and provide current contact information for, organizations and individuals who could be rapidly mobilized to identify the attacking agent and those who would be available to assist with the actual decontamination.

Finding 12-3

Acceptance of the decision to reoccupy a facility will be more successful if an Operations Working Group is formed before an event occurs, and if that group includes people with scientific, technical, and medical expertise and those whose daily lives would be affected by contamination of the airport.

Recommendation 12-3

Planning should identify the interested parties, form them into a working group, and have them interact regularly in anticipation of coming together to guide an actual recovery effort. That effort should be executed in a manner designed to maximize trust among the various participants and stakeholders.

Appendix D

Other Relevant Case Studies

Books could be written about the cases of contamination and decontamination that are relevant to the charges to the Committee on Standards and Policies for Decontaminating Public Facilities Affected by Exposure to Harmful Biological Agents: How Clean is Safe? Here we have selected four relevant studies, chosen largely because committee members are expert in them. Although we can draw some lessons regarding decision making and acceptability of risk, there are limits to the relevance of the cases. Some of them are discussed at the end of this appendix.

BINGHAMTON STATE OFFICE BUILDING

In February 1981 a switch gear failed in the mechanical room of an 18-story office building in Binghamton, New York, creating an electrical arc that lasted for 20 to 30 minutes. Because the building was occupied mostly by state agencies, state officials called it the BSOB (Binghamton State Office Building) (Clarke, 1989). The temperature in the mechanical room rose to an estimated 2000°F, causing a ceramic bushing on a nearby transformer to crack. About 180 gallons of the transformer's coolant, which contained polychlorinated biphenyls (PCBs), leaked out. The intense heat vaporized the coolant, which then mixed with soot produced from burning wires. The fire alarm triggered the opening of hatches on the roof, which were above the stairwells, and the smoke was sucked from the stairwells. When firefighters opened the door to the mechanical room, the BSOB effectively became an 18-story chimney, drawing the contaminated soot up the stairwells, distributing it to the building's ventilation system and

thence throughout the building. The BSOB was now contaminated with the toxin-laden soot. Closed file cabinets, locked desk drawers, even the spaces between each floor, used as plena for normal air circulation, were contaminated. In addition to PCBs, the contaminants contained furans and dioxins. The BSOB would not reopen for 13 years. The building had cost $17 million to build and about $50 million to decontaminate.

The Binghamton case was marked by several risk communication problems. State officials immediately began a cleanup effort, but they used relatively untrained building maintenance workers for the effort. The two local papers soon ran stories of cleanup workers wearing protective suits into nearby uncontaminated buildings to change clothes or use the restroom. The cleanup was poorly supervised; some cleanup workers stole contaminated cash and lottery tickets, and some consumed food and smoked cigarettes in the BSOB. Entrances to the building were not tightly controlled, so nearly 500 people were exposed to the toxins by the time state officials truly closed the building, three weeks after the fire.

In the interim, Governor Hugh Carey offered "here and now to walk into Binghamton, to any part of that building, and swallow an entire glass of PCB and then run a mile afterwards...I'd like to meet that local health officer who put that building in that...If I had a couple of willing hands and a few vacuum cleaners I'd clean that building myself..." Similar problems would characterize a medical surveillance program of those exposed in Binghamton. It also appeared to Binghamton residents that the state was not taking their concerns seriously. The day after the fire, the state health commissioner flew to Binghamton to survey the situation, held a press conference, put other people in charge, and returned to Albany.

State officials had incited distrust among Binghamton's citizens, the media, the county medical society, the Binghamton city council, the Broome County Health Department, and unions by belittling possible dangers and pursuing courses of action that were not conservative with respect to the technical science or to risk communication.

FORT DETRICK: U.S. ARMY BIOLOGICAL WARFARE LABORATORIES

From March 1943 to July 1972 there were several anthrax accidents at the U.S. Army's Biological Laboratories at Fort Detrick, Maryland. The laboratories' mission was to conduct offensive and defensive research with highly pathogenic agents or their toxins. Initially, safety procedures, vaccines, medical treatment regimens, antibiotics, and containment facilities were limited, and there were many unknown operational elements and unrecognized risks to employees (military and civilian). The at-risk population in the laboratories was about 1500-1700 people.

According to accounts made available to the committee, the decontamina-

tion efforts at Fort Detrick were technical and social successes. The buildings were effectively rid of pathogenic agents, and the program was trusted by employees at all levels.

Several factors contributed to those successes. Great precautions were taken to avoid or minimize activities that might compromise safety, cause damage to facilities, allow release of agents into the environment, or permit cross-contamination among research materials and laboratory animals. A dedicated, well-educated, large (up to 30 people) scientific safety staff was appointed at the start of the program. The staff members ranged from well-trained laboratory technicians through PhDs; a physician served as the safety director. The responsibilities for safety included the examination of task and the conduct of research to evaluate hazards associated with laboratory operations, production, equipment, and facilities design concepts. Safety staff also were to be readily available to all employees outside the chain-of-command structure to address each safety concern. That policy provided a forum for evaluation of employee concerns and for the identification of observed deficiencies, regardless of magnitude. It was also a place in which employees' inquires were answered. They received assistance and were provided with daily safety awareness.

With that program established, all post employees, both military and civilians, shared sincere trust in the safety staff. The safety staff were dedicated and accessible, and they gained experience and knowledge during their involvement in every aspect of post operations and research activities. Their procedures and decisions were transparent to those who might have been affected. Because of their partnership in the facility's work, the safety staff were placed at a greater risk to multiple agent exposures than were other employees on the post, thereby eliminating the concern about risk exposure and management trust because of their firsthand understanding of the hazards.

A philosophy and an approved operating policy existed that no reprisal, punishment, or fault finding was to be promulgated following an accident, judgment error, or equipment or facility damage. The policy was conceptualized by upper management because of the high-risk research mission. It was also seen as a way for all employees to learn from every untoward experience and thus to prevent recurrence. The policy was an exception approved for Fort Detrick by the Military and Civil Service Commission. The policy promulgated reporting of incidences to the safety staff for evaluation and effectively promulgated trust at all levels.

A comprehensive medical surveillance program was established from the beginning of the Biological Laboratories. The program encompassed prophylaxis and vaccinations, complete medical surveillance for any suspected or known illness, and complete treatment for known or suspected illness. Before any employee could seek medical services from a private physician, he or she had to obtain clearance from the post physicians. Employees essentially had free medical care because of the willingness and responsibility of the post physician to rule

out all possibility of a laboratory-acquired illness. The post maintained a comprehensive medical staff, an outpatient clinic, and a complete isolation/quarantine hospital.

A biological safety research program was operated to assess all operational aspects, including equipment and facilities development, and to investigate each laboratory or production procedure. The program evolved into the scientific discipline now called "biological safety." It identified procedures to ensure safety in every component of work with pathogenic agents, including work with pathogens and their toxins, genetic manipulations, and production of agents and vaccines. The safety elements are applicable to the biomedical and veterinary disciplines and to evaluations against bioterrorism.

GRUINARD ISLAND, SCOTLAND

In 1942, the War Department of the United Kingdom appropriated from a private owner Gruinard Island, a rocky island about 2 km long and 1 km wide lying just off the northwest coast of Scotland. Before World War II, Gruinard was used for sheep grazing, rough shooting, fishing, collecting bird eggs, and as a picnic spot (Pearson, 1990).

In 1942 and 1943 the British government conducted trials on Gruinard to evaluate the potential use of airborne spores of *B. anthracis*; downwind of bomblet detonation, air was sampled and sheep were exposed (Manchee et al., 1994). The result was light surface contamination over much of the ground, with a majority of material scattered over the ground in the form of large globules of spore slurry in the immediate vicinity and downwind of the detonation point (Manchee et al., 1994). Soil samples taken in 1943, 1944, and 1946 indicated high levels of contamination. Because *B. anthracis* is persistent, it was reasonable to assume it would remain in the soil for a long period of time.

The U.K. Ministry of Supply had purchased Gruinard for £500, with the understanding that the owner could repurchase it for the same amount within 6 months of its being declared "fit for habitation by man and beast" (Manchee and Stewart, 1988; Pearson, 1990). In 1945, the owner sought return of the island. But annual soil sampling between 1946 and 1969 showed persistent contamination, although the number of spores was slowly declining. An extensive survey in 1979 showed that most of the island was not contaminated (Manchee et al., 1994), and that spore contamination was confined to area of about 3 acres (Pearson, 1990). The Ministry of Defence commissioned an Independent Advisory Committee in 1985 to facilitate the return of Gruinard to civilian ownership. The committee reviewed scientific data regarding contamination, advised on and verified decontamination procedures, and advised on the prospect of the land's return to civil ownership and agricultural use (Pearson, 1990). Two areas were identified for remediation: a larger zone around and including the detonation area and the paddock area where exposed sheep were kept (Manchee and Stewart, 1988).

In 1986 the British tried to decontaminate Gruinard: *B. anthracis* spores were inactivated by drenching the soil with fluid biocides (the solution was 5% formaldehyde in seawater). Subsequent sampling revealed pockets of surviving spores which were then treated with undiluted formalin (Manchee and Stewart, 1988; Manchee at al., 1994).

In 1986-1987, decontamination was verified using the following measures: Soil samples were tested; the sera of indigenous rabbits were examined for antibodies to anthrax—none were found; and a local farmer grazed 40 sheep on the island for 6 months, with no ill effect (Pearson, 1990).

In 1988 the Independent Advisory Committee issued its final report, announcing that ". . . we believe that chances of persons or animals contracting anthrax on Gruinard Island are so remote that the island can be returned to civil use" (Pearson, 1990). In 1990 Gruinard was repurchased by heirs of the previous owner (Pearson, 1990). The property transfer, however, has not been without controversy. According to Willis (2002), "some doubts remain locally about the extent and effectiveness of the clean-up process, along with a legacy of bitterness."

HAZELTON RESEARCH PRIMATE QUARANTINE UNIT

In 1989, monkeys began to die at the Hazelton Research Unit in Reston, Virginia. At first, officials thought the problem was a common monkey virus, but samples sent to the U.S. Army Medical Research Institute of Infectious Diseases soon revealed the animals were dying of Ebola virus. The situation worsened when officials realized the virus was spreading through the air; one monkey handler became ill (Alexander, 1998). The monkeys were euthanized and the building was decontaminated before its destruction. The Centers for Disease Control and Prevention, U.S. Department of Health and Human Services, and the U.S. Army oversaw the decontamination process; several other federal organizations also were involved. The building was sealed, hosed down with concentrated bleach, and then decontaminated with paraformaldehyde, after which it was sealed for 3 days. The Hazelton facility cost $12 million to build and the owner tried to sell it for about $4 million. At the end of 6 years, and on the market for $1 million, the owner decided to bulldoze the building and sell the land.

CONCLUSIONS

All of the cases reviewed here demonstrated the central role that risk communication, transparency of decision making, and trust play in establishing an acceptable and safe level of decontamination. At Hazelton, officials could not overcome the stigma of Ebola. At Gruinard, officials could not gain the trust of local people. Both problems involved a lack of trust.

The Binghamton case was characterized by lack of transparency and by dismissive postures on the part of officials toward the concerns of the public and

workers. The result was mistrust that contributed to the building being closed for 13 years. If New York officials had instituted something similar to this report's recommendations regarding an analytic deliberative process, many of the problems experienced in Binghamton could have been avoided. Because the Binghamton State Office Building housed state agencies, closing it had few economic consequences; it *could* remain closed for so long without severe disruption. That would not be true for the contamination of a major American airport, and the need to reopen would be more pressing.

REFERENCES

Alexander, L. 1998. Decontaminating Civilian Facilities: Biological Agents and Toxins. IDA Paper P-3365. Alexandria, Virginia: Institute for Defense Analyses.

Clarke, L. 1989. Acceptable Risk? Making Decisions in a Toxic Environment. Berkeley, California: University of California Press.

Manchee, R.J., and D.P. Stewart. 1988. The decontamination of Gruinard Island. Chemistry in Britain July: 690-692.

Manchee, R.J., M.G. Broster, A.J. Stagg, and S.H. Hibbs. 1994. Formaldehyde solution effectively inactivates spores of *Bacillus anthracis* on the Scottish Island of Gruinard. Applied and Environmental Microbiology 60(11): 4167-4171.

Pearson, G.S. 1990. Gruinard Island returns to civil use. The ASA Newsletter 5.

Willis, E.A. 2002. Landscape with dead sheep: what they did to Gruinard Island. Medicine, Conflict and Survival 18(2): 199-210.

Appendix E

Were the 2001 Anthrax Exposures Consistent with Dose–Response: The Case for the AMI Building

Risk assessment methodology can be assessed for validity by examining the predicted illness burden from application of dose-response relationships and estimates of exposure with the observed illness burden. A case in point is the contamination of the American Media, Inc. (AMI), building in Boca Raton, Florida. In that incident, there were 2 known cases of inhalation anthrax.

From the information available, it appears that exposure occurred when an envelope containing *Bacillus anthracis* spores was opened in the mailroom of the building. The duration of exposure is not known, but is assumed to have been one, 8-hour working shift. Other key parameters that characterize the risk are listed in Table E-1.

If the anthrax spores were immediately released into the air within the mailroom, then the instantaneous initial concentration would have been as follows:

$$\frac{m_0 \rho f}{V_{room}} = \frac{(1gm)\left(10^{11}\frac{\#}{gm}\right)(0.2)}{4290m^3} = 4.67 \bullet 10^6 \frac{\#}{m^3}$$

The ventilation rate in the room (ACH) results in the dilution of the aerosolized spore concentration, as shown diagrammatically in Figure 7-3. Using an exponential dilute-out curve (based on a completely mixed room volume), the 8-hour average concentration is computed to be $8.2 \bullet 10^5$ #/m^3.

TABLE E-1 Point Values of Input Parameters

Grams of Spores	m_0	1 gm	Estimated Amount in Single Envelope Released in Mailroom
#/gram	ρ	10^{11}	Spore without additive would be ca 10^{12}/gram
Fraction aerosolized	f	0.2	Unknown
Air changes/hour	ACH	1	Based on common ventilation rates
Inhalation volume	V	2.4 m^3	8 hours exposure at normal adult breathing rate
Dose–response parameter	k	$7.16 \bullet 10^{-6}$	From analysis of the Druett data on monkeys
Volume into which release occurred	V_{room}	4290 m^3	Based on floor plans, about 10% of the building volume comprised the mailroom
Individuals exposed	P	10	Based on 10% of the total estimated number of employees

When that concentration is multiplied by the inhalation volume for an exposure by an individual worker, the average number of spores inhaled (the dose) is computed as follows:

$$d = \left(2.4m^3\right)\left(8.2 \bullet 10^5 \frac{\#}{m^3}\right) = 1.97 \bullet 10^6$$

Using the best estimate for the dose–response relationship (in the exponential dose-response model), the risk (per individual exposed) is computed to be:

$$1 - \exp\left(-\left(7.16 \bullet 10^{-6}\right)\left(1.97 \bullet 10^6\right)\right) = 0.9999992$$

This computation suggests that all individuals so exposed should have contracted inhalation anthrax. However, it is obvious that several parameters and assumptions have gone into the production of this point estimate. If the uncertainties in each input were considered, what would be the estimated confidence limit for the number of persons who could have become ill?

There are two approaches to this assessment. In the first approach, all of the point estimates in Table E-1 are used and, in addition, an "effectiveness factor"

TABLE E-2 Input Parameter Distributions

Grams of Spores	m_0	$N(1,0.3)$
#/gram	ρ	$10^{N(11,0.3)}$
Fraction aerosolized	f	$B(5,20)$
Air changes/hour	ACH	$Tr(0.5,1,3)$
Inhalation volume	V	$Tr(2,2.4,3)$
Dose-response parameter	k	$\exp\left[N\left(\log\left(7.16 \bullet 10^{-6}\right)1.5\right)\right]$
Volume into which release occurred	V_{room}	$N(4285,1285)$
Individuals exposed	P	$Bin(100,0.1)$

$N(mu,s)$: normal distribution with mean=mu, standard deviation=s
$B(a,b)$: beta distribution with parameters a and b (mean = $a/(a+b)$)
$Tr(L,M,U)$: triangular distribution with minimum=L, mode=M, maximum=U
$Bin(N,p)$: Binomial distribution with total N and "success" probability p (mean=Np)

for the inhaled anthrax spores is assumed, such that the dose–response equation becomes modified to yield (for the individual risk) the following:

$$1-\exp\left(-\eta k d\right)$$

where η is the effectiveness (which may be regarded as the apparent potency of the spores from the AMI building relative to those used in the animal infectivity trials). It can then be asked what would be the value of η be if the dose (d) and dose–response parameter (k) remained as above, and the predicted risk were such to produce 2 cases in the 10 individuals exposed (i.e., a risk per individual of 0.2)? If the effectiveness were 0.016, then the estimated and observed risk would be equal: The potency of the AMI spore preparation may have been 1.6% of that used in the monkey experiments.

Another approach would be to posit distributions for each of the key inputs. There are few exact data on which to ground these distributions, and hence the subsequent calculation should be considered illustrative, but it should serve to motivate a better estimate of the input assumptions and their distributions.

Table E-2 provides distributions for each of the inputs used in an overall assessment of uncertainty of risk.

Using these input distributions, the distribution of predicted cases can be computed using a Monte Carlo simulation. The cumulative distribution of predicted cases is shown in Figure E-1. Although the observed number of cases (2) is below the mean and the median number of cases that would have been estimated to occur, there is nonetheless (given the uncertainty in the inputs) the potential for this low number of cases to have occurred. Further refinement of the inputs (Table E-2) would enable one to determine how unusually low the observed number of cases might have been.

As part of the Monte Carlo run, a sensitivity analysis can be conducted in which the correlation between each of the inputs (considered separately) and the output (# of cases) is examined. The results are shown in Figure E-2. It is apparent that the two most important drivers of the risk are the number of individuals exposed and the dose–response parameter (ln$k$ - the natural logarithm of the dose response parameter, k). This sensitivity analysis can be useful in assessing how resources should be deployed in any further exploration of the problem.

This analysis suggests that the quantitative microbial risk assessment approach is plausibly supported by the AMI incident. Clearly, there are significant

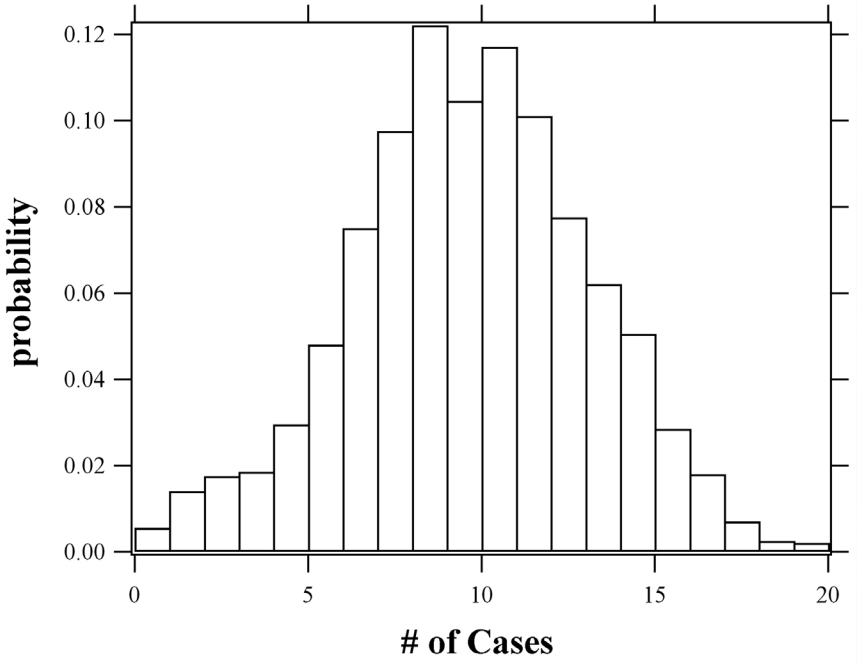


FIGURE E-1 Histogram of predicted number of cases.

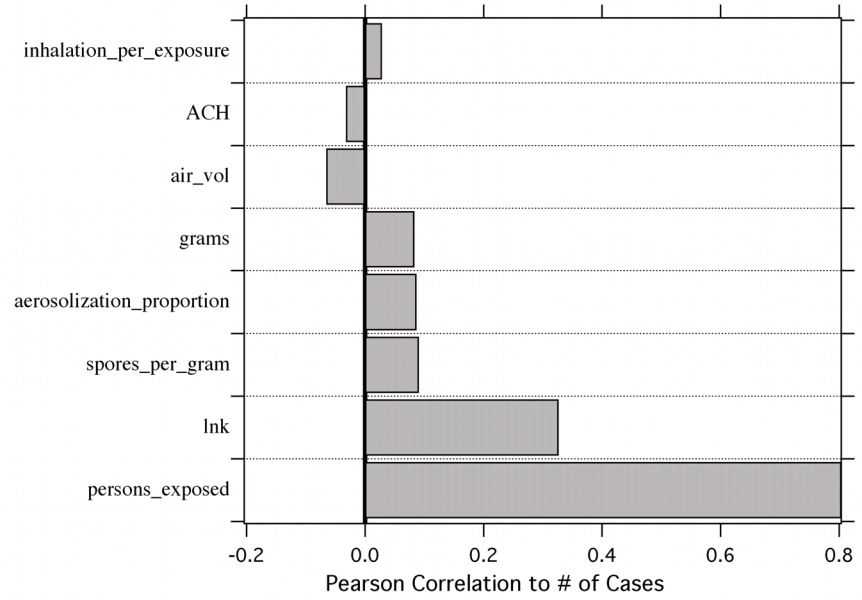


FIGURE E-2 Sensitivity analysis of inputs.

uncertainties. Some of these relate to the need to better quantify the exposures (persons at risk, spore density, aerosolization fraction); however, others clearly relate to the intrinsic properties of the agent(s) themselves (i.e., the dose-response parameter). Hence, it would be useful to develop a better understanding of the dose–response relationships for potential bioterrorist agents, and their associated uncertainties and variabilities.

Appendix F

Biographical Sketches of Committee Members

Kenneth Berns, University of Florida, Chair
Kenneth Berns is Director of the Genetics Institute and Professor of Molecular Genetics and Microbiology at University of Florida (UF). He is a former Vice President for Health Affairs and Dean of the College of Medicine at University of Florida. Dr. Berns has served as president and chief executive officer at Mount Sinai Medical Center, CEO at Mount Sinai Hospital, and CEO of the Mount Sinai School of Medicine in New York. He holds both a medical degree and a doctorate in biology from The Johns Hopkins University. He, along with eminent scholar Nicholas Muzyczka, won international recognition for work they performed at UF in the early 1980s when they modified the adeno-associated virus, or AAV, for use as a vector for carrying corrective genes. He is an American Association for the Advancement of Science Fellow and he has received the Distinguished Service Award from National Board of Medical Examiners. He served as President of American Society for Microbiology in 1996-97. He has also served on numerous NRC committees, including the Committee on Assessment of Future Needs for *Variola* (Smallpox) Virus. He is a member of the National Academy of Sciences and the Institute of Medicine.

Ronald M. Atlas, University of Louisville
Ronald M. Atlas is Professor of Biology and graduate dean at the University of Louisville. He received a B.S. from the State University of New York at Stony Brook and an M.S. and a Ph.D. from Rutgers University. After one year as a National Research Council Research Associate at the Jet Propulsion Laboratory he joined the faculty of the University of Louisville in 1973. He is a member of

the American Academy of Microbiology and was the recipient of the American Society for Microbiology award in Applied and Environmental Sciences. He recently served as president of the American Society of Microbiology. His recent studies have focused on the application of molecular techniques to environmental problems. His studies have included the development of "suicide vectors" for the containment of genetically engineered microorganisms and the use of gene probes and the polymerase chain reaction for environmental monitoring, including the detection of pathogens and indicator bacteria for water quality monitoring. He was a member of the NRC committee that recently released the report "Biotechnology Research in an Age of Terrorism."

Manuel S. Barbeito, Independent Consultant

Manuel S. Barbeito is an independent Biosafety Consultant, Registered Microbiologist, and Certified Biological Safety Professional. He received his B.S. in microbiology from Pennsylvania State University and took postgraduate courses at University of Maryland and New York University. He worked with the U.S. Army Corps of Engineers, U.S. Postal Service, and Consolidated Safety Services for the U.S. State Department on the decontamination of facilities and equipment contaminated with *Bacillus anthracis*. In 1996, he retired as Biological Safety Officer from USDA-Agriculture Research Services as the Biological Safety Officer where he served as the agency's technical expert for construction and use of containment facilities and for decontamination and sterilization of laboratories and materials. He worked as microbiologist in the Agent Control Division at Fort Detrick from 1956 to 1972 in the biological, chemical, and industrial safety program for personnel handling pathogenic microorganisms and biological toxins. From 1969 to 1972 he worked with colleagues on the decontamination of Fort Detrick containment facilities following their extensive use with numerous pathogenic organisms and toxins.

Jacqueline Cattani, University of South Florida

Jacqueline Cattani is Professor of Occupational and Environmental Health and Director of the Center for Biological Defense in the College of Public Health at University of South Florida (USF). She received her Master's Degree in Economics from the University of California, Santa Barbara, and her MPH and Ph.D. in epidemiology from the University of California, Berkeley. Prior to joining USF, she served as epidemiologist/scientist for the UNDP/World Bank/WHO Special Programme on Research and Training in Tropical Diseases (TDR) at the World Health Organization, Geneva, Switzerland, as a faculty member in the Department of Tropical Public Health at the Harvard School of Public Health, and as malaria epidemiologist at the Papua New Guinea (PNG) Institute of Medical Research in Madang, PNG. Her current research is on dual-use disease surveillance for bioterrorism and other public health emergencies, the design, development, and evaluation of educational and training materials on biodefense for

first responders, and management of research on a broad spectrum of technologies with applications to rapid recognition and response to potential bioterrorist events.

Lee Clarke, Rutgers University

Lee Clarke, Ph.D.., is Associate Professor in sociology at Rutgers University. Clarke writes about organizations, risk communications, culture, and disasters. His early work concerned how decision makers choose among risks in highly uncertain environments. Publications include: *Acceptable Risk? Making Decisions in a Toxic Environment*, University of California Press; *Organizations, Uncertainties, and Risk*, edited by James F. Short, Jr. and Lee Clarke, Boulder: Westview Press; "Explaining Choices Among Technological Risks," *Social Problems*; "Oil Spill Fantasies," *Atlantic Monthly*; "Sociological and Economic Theories of Markets and Nonprofits," *American Journal of Sociology*, "The Disqualification Heuristic: When Do Organizations Misperceive Risk?" *Research in Social Problems and Public Policy*, "Prosaic Organizational Failure," *American Behavioral Scientist*, The Myth of Panic, *Contexts*. Clarke's most recent edited book is a hard-bound issue of *Research in Social Problems and Public Policy, Terrorism, and Disaster: New Threats, New Ideas*, Elsevier Press. His most recent book is *Worst Cases: Inquiries into Terror, Calamity, and Imagination*, to be published by University of Chicago Press, fall 2005. Clarke has written, and frequently lectures about, organizational failures, leadership, terrorism, panic, civil defense, evacuation, community response to disaster, organizational failure, and the World Trade Center disaster. He has also worked with the U.S. Department of Energy in fashioning a research agenda for problems of long-term stewardship of contaminated properties. Clarke's work was featured in the *New York Times* in May 2003 and the *Harvard Business Review* in June, 2004. Lee Clarke exists virtually at http://leeclarke.com.

Christopher J. Davis, CUBRC, Inc.

Christopher J. Davis is the Chief Scientist and Director of Biomedical Research at CUBRC, Inc. and President of Intuitive Intelligence International, a management consulting company providing risk assessment, mitigation and consequence management, policy analysis, technology acquisition strategy and R&D investment advice, and market and business development strategy and advocacy. He received his M.D. from University of London, King's College Hospital Medical School and his Ph.D. in Neuropharmacology from University of Oxford. Christopher Davis is a recognized international authority on biological warfare and biodefense issues. He has 17 years experience in military medicine as a specialist in nuclear, biological, and chemical defense, and retired from the Royal Navy as a senior Surgeon Commander in 1996. As a member of the Defense Intelligence Staff for 10 years he was directly responsible for the collation, analysis and assessment of all global source intelligence on biological weapons and the medi-

cal aspects of CB warfare and terrorism. He sits on the National Academy of Sciences Working Group on Biological Weapons and is a Professor in the Department of Molecular and Microbiology at George Mason University's National Center fo Biodefense. He is also a member of the Board of Advisors of The Critical Decision Institute, Oregon. He was awarded the Order of the British Empire in 1992 for his contributions to international security and is a former Visiting Professor of Medicine at Johns Hopkins University's Center for Civilian Biodefense Strategies.

Patricia Fellows, DynPort Vaccine Company, LLC

Patricia Fellows is a manager of nonclinical research at Dynport Vaccine Company, LLC in Frederick, Maryland. She received her M.S. in Biomedical Science from Hood College in 1992. She has worked in the field of biomedical science for 16 years, in both government and private laboratories. Much of her research efforts and interests have focused on *Bacillus anthracis*. She has been involved in the development and testing of new anthrax vaccine candidates in a variety of animal models. She served as a member of an Integrated Project Team providing assistance to the manufacturer of the current licensed human anthrax vaccine with respect to the potency assay used to release lots of vaccine for human use. In her current capacity as manager of nonclinical research, she serves as a lead in the planning, development, and management of nonclinical studies in support of new vaccine candidates.

Charles N. Haas, Drexel University

Charles N. Haas is the Betz Chair Professor of Environmental Engineering at Drexel University. He was formerly a professor and acting chair in the Department of Environmental Engineering at the Illinois Institute of Technology. He received a B.S. in biology and an M.S. in environmental engineering from the Illinois Institute of Technology and a Ph.D. in environmental engineering from the University of Illinois. His research interests include bioterrorism—assessment of risks from exposures to deliberately released agents (e.g., anthrax) and engineering analysis and optimization of chemical decontamination schemes—drinking water treatment, and hazardous and industrial waste treatment. Dr. Haas has served on several NRC committees, including the Committee to Review the New York City Watershed Management Strategy, the Committee on Drinking Water Contaminants, and the Committee on Toxicants and Pathogens in Biosolids Applied to Land.

Thomas V. Inglesby, University of Pittsburgh Medical Center

Thomas V. Inglesby, M.D., chief operations officer of the Center for Biosecurity of the University of Pittsburgh Medical Center (UPMC), previously served as deputy director of the Johns Hopkins Center for Civilian Biodefense Studies, and as a faculty member at the Johns Hopkins University School of Medicine. Dr.

Inglesby was a principal designer, author, and facilitator of the Dark Winter Exercise of June 2001. He is lead author of the article "A Plague on Your City: Observations from TOPOFF," which appeared in *Clinical Infectious Diseases* in January 2001. Dr. Inglesby has acted as an advisor and consultant to federal and state agencies on issues related to bioterrorism preparedness. He is a member of the committee revising "The 1996 Olympic Clinical Treatment Protocols for Casualties Resulting from Terrorist Incidents Involving Weapons of Mass Destruction." Dr. Inglesby is a board-certified internist and infectious disease specialist. He received his B.A. from Georgetown University in 1988 and his M.D., at the Columbia University College of Physicians and Surgeons in 1992. He completed his internal medicine residency at the Johns Hopkins Hospital. In 1996-1997, he was an assistant chief of service in the department of medicine at the Johns Hopkins School of Medicine. He completed specialty training in infectious diseases at the Johns Hopkins School of Medicine.

Harvey W. Ko, Johns Hopkins University Applied Physics Laboratory
Harvey W. Ko is the Chief Scientist at the Johns Hopkins Applied Physics Laboratory (ARL) National Security Technology Department. He obtained a B.S. in electrical engineering and a Ph.D. in electrophysics from Drexel University in 1967 and 1973, respectively. Since joining APL in 1973, he has been active in chemical and biological defense, biomedical engineering, nonacoustic antisubmarine warfare, ocean electromagnetics, and radar propagation. He holds eight patents in biomedical engineering for various technology methods in biodetection, brain edema, osteoporosis, magnetoencephalography, and magnetic holography. His current research interests include prostate bioimpedance, low-frequency electromagnetic holography, chemical and biological detection, and immune building countermeasures. As manager of the counterterrorism and counterproliferation efforts, he is involved in the development of biological and chemical mass spectrometers and miniature affinity chromatography biosensor systems, the biological and chemical characterization of operating environments, the evaluation of biological neutralization methods, and the characterization of chemical and biological aerosols. He is a member of the IEEE and the Association for the Advancement of Medical Instrumentation. He has had both functional line supervisory and programs management responsibility and has been a member of numerous government panels. He is also a guest lecturer in The Whiting School of Engineering and The Bloomberg School of Public Health.

R. Paul Schaudies, SAIC
Dr. Schaudies is Assistant Vice President and Division Manager of the Biological and Chemical Defense Division at SAIC. His division focuses in three major business areas, contract biomedical research, technology assessments, and scientific studies. He was key in establishing the levels for reentry into the Hart Building and is a nationally recognized expert in the fields of biological and

chemical warfare defense. He has served on numerous national-level advisory panels for the Defense Intelligence Agency, the Defense Advanced Research Projects Agency, and the Department of Energy. He has 14 years bench research experience managing laboratories at Walter Reed, Walter Reed Army Institute of Research, and as a Visiting Scientist position at the National Cancer Institute. He served for 13 years on active duty with the Army Medical Service Corps and separated from service at the rank of Lieutenant Colonel-select, and spent 4 years with the Defense Intelligence Agency as Collections Manager for Biological and Chemical defense technologies. As such, he initiated numerous intra-agency collaborations that resulted in accelerated product development in the area of biological warfare agent detection and identification.

Monica Schoch-Spana, University of Pittsburgh Medical Center
Dr. Schoch-Spana is a Senior Fellow with the Center for Biosecurity of the University of Pittsburgh Medical Center. She received her B.A. in anthropology from Bryn Mawr College, and Ph.D. in cultural anthropology from The Johns Hopkins University. Dr. Schoch-Spana has led research, education, and advocacy efforts to encourage within bioterrorism response policy and planning circles greater consideration of the general public's capacity to confront bio attacks constructively—a realm she has termed "the people's role in biodefense." She has encouraged authorities to move beyond the prevailing assumption of a panic-prone public and plan proactively for a positive population response to public health crises. Dr. Schoch-Spana organized the 2003 national leadership summit, The Public as an Asset, Not a Problem. She currently chairs the multidisciplinary Working Group on "Governance Dilemmas," a group charged with enhancing the ability of mayors, governors, and health authorities to reduce the socially disruptive quality of biological attacks and to safeguard the public's trust and cooperation during the government's response. She has served as a technical advisor to the Ad Council's national campaign on emergency preparedness, in conjunction with the Department of Homeland Security.

John D. Spengler, Harvard School of Public Health
John D. Spengler is the Akira Yamaguchi Professor of Environmental Health and Human Habitation in the Department of Environmental Health, at Harvard University's School of Public Health. He received a B.S. in physics from the University of Notre Dame, an M.S. in environmental health sciences from Harvard University, and a Ph.D. in atmospheric sciences from the State University of New York, Albany. He has conducted research in the areas of personal monitoring, air pollution health effects, aerosol characterization, indoor air pollution, and air pollution meteorology. More recently, he has been involved in research that includes the integration of knowledge about indoor and outdoor air pollution as well as other risk factors into the design of housing, buildings, and communities. He uses the tools of life-cycle analysis and risk assessment and

activity-based costing as indicators to measure the sustainable attributes of alternative designs, practices, and community development. He serves as advisor to the World Health Organization on indoor air pollution, personal exposure, and air pollution epidemiology, and he has served as either a member or consultant on various U.S. EPA Science Advisory Board committees.

James Tucci, K and J Consulting Services
James Tucci is President and Chief Engineer of K and J Consulting Services. He is a Senior Associate Instructor for the U.S. Department of Transportation, Transportation Safety Institute, and the Federal Transit Administration's Office of Safety and Security, teaching transit system security and response to weapons of mass destruction. His expertise is concentrated in the areas of transit environmental regulatory compliance, Occupational Safety and Health Administration (OSHA) compliance, transit system safety/security compliance audits and investigations, pro-ject management, alternative fuels incident investigation and facility inspections and system safety auditing. He is also under contract to the Federal Bureau of Investigation as a counterterrorism consultant for the transit industry and is assisting with security/ventilation design engineering for the East Side Access Project in New York City. He formerly worked for Centers for Disease Control, U.S. Department of Labor/OSHA, and Transit Safety/Security Division of the Transportation Safety Institute of the U.S. Department of Transportation. He received a B.S. in environmental engineering/environmental management from LaSalle, and an M.S. in analytical chemistry.

James Wilding, Metropolitan Washington Airports Authority
James Wilding retired as President of the Metropolitan Washington Airports Authority (MWAA). He holds a degree in Civil Engineering from Catholic University in Washington. He spent his entire career at the two Washington airports, National and Dulles. He worked for the Federal Aviation Administration (FAA) from 1959 to 1987. He was Deputy Director in both National and Dulles Airport from 1974 to 1979 and became President and Chief Executive Officer in 1979. In 1987, he began working with MWAA, when it was formed to take over the two airports from FAA, until he retired in May 2003. He has served in a variety of industry, civic, business, and transportation organizations, including the Executive Committee of TRB.