Terrorism and the Chemical Infrastructure: Protecting People and Reducing Vulnerabilities

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Terrorism and the Chemical Infrastructure

PROTECTING PEOPLE AND REDUCING VULNERABILITIES

Committee on Assessing Vulnerabilities Related to the
Nation's Chemical Infrastructure

Board on Chemical Sciences and Technology
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Preface

The Committee on Assessing Vulnerabilities Related to the Nation's Chemical Infrastructure was convened by the National Academies to respond to a request from the Department of Homeland Security (DHS) Science and Technology Directorate (S&T). The directorate sought assistance in making research, development, and technology investments that would help secure the nation's chemical infrastructure and safeguard against the consequences of a terrorist attack on that infrastructure. The focus was on securing the nation's infrastructure and economy against terrorist attack and other catastrophic loss by examining the chemical supply chain to identify key chemicals and chemical processes whose disruption could result in catastrophic levels of casualties or catastrophic economic damage. Specifically, this review considers

- Major vulnerabilities and points of weakness in the chemical supply chain that could lead to catastrophic consequences;
- The likely impact of a significant disruption in the supply of these chemicals and processes;
- Actions (procedures, policies, technology deployment) to help prevent disruption in the supply of these chemicals and processes, and to mitigate loss and injury should such disruption occur;
- Incentives and disincentives that affect private sector decisions to take preventive and mitigating actions; and

- Areas of scientific, engineering, and economic research and development that might advance the nation's capability to protect against such losses and minimize their impact.

The committee's full statement of task can be found in Appendix B.

I met with DHS S&T representatives several times early in the study process to discuss the statement of task, data availability, and the department's objectives in commissioning this study. Based on these discussions and from discussions with DHS representatives at the committee's first meeting, it was agreed that this study should complement and not attempt to duplicate other ongoing activities such as the DHS Risk Analysis and Management for Critical Asset Protection (RAMCAP) and Environmental Protection Agency's (EPA's) Off-Site Consequence Analysis. Thus, the committee did not attempt to assess the effectiveness of current protective measures; although called for in the statement of task; this was a part of the DHS RAMCAP effort, which DHS representatives made clear should not be duplicated. As the statement of task indicates, the focus of this review is on the vulnerabilities of the supply chain as a whole rather than the vulnerability of individual chemical plants.

The committee did not have access to the results or preliminary results of the DHS RAMCAP exercise or to the data upon which it is based. Similarly the committee did not have access to EPA's Off-Site Consequence Analyses. Nor did the committee rely on proprietary or other non-disclosable information from chemical industry representatives upon which to base its report. This report is based solely on open-source information, and the committee's intention was to write a report whose distribution could be unrestricted. This report represents the dedicated time and effort of all the committee members. The members responded gracefully to the request to submit to a demanding schedule of meetings in a short time period, without compensation and while continuing to attend to the duties of their regular jobs. I am grateful for their work and thoroughly enjoyed the stimulating discussions we had as a part of this process.

Linda Capuano
Chair

POSTSCRIPT ON HURRICANES KATRINA AND RITA

This manuscript was being finalized and sent to review as Hurricane Katrina decimated the Gulf Coast and was in reviewers' hands when Hurricane Rita hit in the first few weeks following that disaster. It is clear that the overall impact of Katrina was catastrophic, although a final casualty figure may never be definitive, and some economic consequences will linger for years. At the time this report was being finalized, the hurricanes' impact on the petrochemical industry was fairly clear, and the largest ripples in the economy due to their disruption had apparently occurred. These two hurricanes' effects on petroleum refineries and on the petrochemical industry are real-life examples of the types of disruption that the Department of Homeland Security envisioned when commissioning this report. As such, the hurricanes' aftermath provides an unfortunate real-life opportunity to learn lessons about the effects of a major disruption in the petroleum supply chain and on the effectiveness of the responses to such an event.

It will take years for researchers to fully tally the cost of these two hurricanes, but events thus far are consistent with the conclusions and recommendations of this report regarding the robustness of the chemical supply chain and the importance of emergency preparedness and response. Lessons learned from these hurricanes and the responses to them provide an opportunity to better understand the resilience of the chemical infrastructure and determine potential opportunities for improvement.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals 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 the published report as sound as possible and to ensure that the report meets institutional standards for 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:

Cheryl Burke, DuPont
Charles Casey, University of Wisconsin
Paul K. Davis, The RAND Corporation
Robert Gallamore, Northwestern University
Yacov Haimes, University of Virginia
Steven Kramer, Institute for Defense Analyses
M. Sam Mannan, Texas A&M University
Guy M. Miller, Heico/Zeeland Chemicals
Martin Sherwin (Retired), W.R. Grace Company
Ellis Stanley, City of Los Angeles Emergency Preparedness Department

Esther S. Takeuchi, Wilson Greatbatch Technologies, Inc.
Beth Turner, DuPont
Oliver Williamson, University of California, Berkeley

Although the reviewers listed above have provided many 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 Dr. R. Stephen Berry, University of Chicago, and Dr. David C. Bonner, Pretium Consulting Services, LLC, Houston, TX. 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 authors and the institution.

Contents

Executive Summary

Since the attacks of September 11, 2001, federal, state, local, and tribal governments, aided by the private sector, have undertaken an unprecedented review of the nation's infrastructure to determine potential targets for future terrorist attacks. At the national level, the Department of Homeland Security (DHS) has divided the nation's infrastructure into 17 categories of critical infrastructures and key resources, one of which is the chemical industry and hazardous materials sector.

The chemical sector is a key part of the national economy. Although its products represent only 2 percent of the U.S. gross domestic product, they underpin most other manufactured goods. Direct products of the chemical industry include plastics, fibers, and drugs, and many more products such as paper, fabrics, cosmetics, and electronics are dependent on the products of the chemical industry.

The chemical sector includes firms that manufacture huge volumes of chemicals intended for many uses—such as major refineries processing thousands of tons of petrochemical feedstocks daily—as well as firms that produce small quantities of materials with highly specific uses, such as small pharmaceutical companies producing products in gram or kilogram quantities after many days of processing and purifying. Some of these chemical products are toxic, flammable, or explosive. The facilities in which chemicals are produced are similarly varied—from refineries covering square miles of land with many high-volume chemicals on-site, to startup companies occupying thousands of square feet in light industrial parks. Products can be transported to their final place of use by truck, rail, pipeline, marine vessel or other means in both large and small quantities.

STUDY CHARGE

This study was requested by DHS to assist the department in characterizing and mitigating the vulnerabilities faced by the nation from its chemical infrastructure (see Appendix B for full statement of task). The study has examined classes of chemicals and chemical processes that are critical to the nation's security, economy, and health; identified vulnerabilities and points of weakness in the supply chain for these chemicals and chemical processes; assessed the likely impact of a significant disruption in the supply chain; identified actions to help prevent disruption in the supply chain and actions to mitigate loss and injury should such disruption occur; identified incentives and disincentives to preventive and mitigating actions; and recommended areas of scientific, engineering, and economic research and development that might advance the nation's capability to protect against such losses and minimize their impact.

This report addresses the most significant general types of vulnerabilities associated with the chemical infrastructure, not site-specific vulnerabilities. Other government and private sector efforts are developing vulnerability and risk assessments that account for site-specific factors such as the amount of chemical on a site and the size of the potentially affected population near a site. This study is intended to supplement those efforts.

POTENTIAL VULNERABILITIES AND POINTS OF WEAKNESS

This report adopts the definition of catastrophic incident outlined in DHS's *National Response Plan*—one that "results in large numbers of casualties and/or displaced persons, possibly in the tens of thousands." Similarly, an economic impact on the order of tens to hundreds of billions of dollars would be considered catastrophic. A catastrophic event is one whose consequences are so extensive that they overwhelm the ability of emergency responders, local and federal government officials, and/or the general public to adequately and/or fully respond in a timely fashion.

Toxic, flammable, and explosive materials present the greatest risk of catastrophic incident.

Casualties within the chemical sector are most readily caused by exploiting the toxic, explosive, or flammable properties of chemicals. By far the largest number of casualties would be anticipated from situations involving toxic inhalation hazards, that is, large-scale release of toxic chemicals in a gaseous form. Damage to infrastructure and subsequent economic loss is caused more readily by the flammable and explosive properties of chemicals.

All scenarios envisioned by the committee with potentially catastrophic consequences were some variation on or combination of one or more of three basic scenarios: (1) release from high-volume storage (either fixed site or in transit); (2) shortage of key chemical or chemical product; and (3) misuse of a small quantity of chemical (tampering or theft). Terrorists could conceivably cause a single terrorist incident or multiple terrorist incidents, geographically co-located or dispersed, simultaneously or over a period of days or weeks. Consequences would be greater with a greater number of events carried out; the difficulty and complexity of such an attack and risk of interception would similarly be greater.

In the absence of specific threat information, it will be most appropriate to invest in mitigation and preparedness for general classes of vulnerabilities.

In the case of either casualties or economic loss, catastrophic levels of consequences are expected only where large quantities of chemicals with toxic, explosive, and hazardous properties are involved. However, social response may amplify the effects of an incident involving even a small quantity of chemicals to the point at which its economic effects, not its casualties, become catastrophic, or at least of national concern.

POTENTIAL IMPACTS OF DISRUPTIONS TO THE CHEMICAL SUPPLY CHAIN

By analogy with past accidents involving the chemical industry, it is possible that a single terrorist incident involving the chemical infrastructure could result in catastrophic loss of life or injuries.

This report discusses scenarios based on historical chemical incidents that serve as existence proofs (but not necessarily upper bounds) for possible consequences of a disruption to the chemical supply chain. By using this approach it is easy to determine that a single chemical event could cause catastrophic casualties. For example, approximately 4,000 people died in the immediate aftermath of the methyl isocyanate gas leak from the Union Carbide India Limited Bhopal plant in December 1984. Injuries have been estimated to range from 200,000 to 500,000 and contributed to an accumulation of 15,000 to 20,000 disaster-related deaths in subsequent years. In this country, an explosion involving 2,300 tons of ammonium nitrate in a Liberty ship at a loading dock in Texas City, Texas, on April 16, 1947, cascaded into widespread destruction of nearby petroleum refineries, chemical production facilities, and another fertilizer Liberty ship, ultimately claiming nearly 600 lives and causing approximately 3,500 injuries—America's worst chemical catastrophe.

The economic effects of a single terrorist incident involving the chemical infrastructure could be significant, but multiple terrorist events would be required to achieve nationally catastrophic economic consequences.

The chemical industry is quite diverse, with redundancies that mitigate the effects of loss of production due to major shutdowns. Where stockpiles do not exist, market forces quickly compensate for loss of production by increased production at another facility of the same or a different company, or by temporary substitution in industrial processes of another chemical with similar properties.

Although a single incident might not result in a nationally catastrophic economic loss, such an incident could result in changes to business and manufacturing processes across the industry, either voluntarily or through regulation. The costs associated with such changes could be significant to individual companies and to local economies, but would not have a major impact on the national economy.

Public response is significant in determining the consequences of attack on the chemical infrastructure.

Public response to any act of terrorism in this country involving the chemical infrastructure will undoubtedly be significant and could invoke both positive and negative consequences. While the impact of a terrorist incident in itself may be linear (that is, the loss of life and injury will be directly related to the size of a chemical release within a given category of chemicals), there may be significant nonlinear social consequences of the incident. These consequences could significantly affect sectors of the economy, such as the negative impact on the travel and airline industries after September 11th. It may also impact public morale, affect the level of trust and confidence in the government's ability to protect its citizens, and exacerbate feelings of vulnerability leading to social (sociological) and psychological effects. Conversely, a well-informed general population that is adequately prepared for such events could decrease negative consequences and unnecessary casualties.

Public authorities will need an understanding of social amplification and attenuation if they wish to successfully manage the aftermath of a chemical attack. Research can support the development of specific guidelines for limiting, and even mitigating, consequences by stimulating a positive public response and preventing negative social amplification.

RECOMMENDATION: In investing in and utilizing behavioral and social science research, DHS should give particular attention to understanding and preparing for the societal response that will occur following a major chemical incident.

ENHANCED EMERGENCY PREPAREDNESS, EMERGENCY RESPONSE, AND DISASTER RECOVERY

Accurate information analysis and communication before, during, and after an event between parties charged with responding and with the public may be the best short-term means to mitigate the possible consequences of an event.

Accurate information analysis and communication consists of several components:

- Acquiring reliable data—in an emergency, this includes reducing data errors and ambiguity to the greatest extent possible;
- Converting the data into integrated information and conclusions;
- Deciding on and communicating appropriate actions; and
- Communicating promptly to the public in an accurate, comprehensible, and believable fashion.

Effective emergency response depends on the rapid analysis of information received in a crisis to determine its relevance and accuracy. This information must also be communicated rapidly and accurately to all necessary parties involved in decision-making, and then integrated into the decision making process to determine an effective response. This is especially true in a chemical attack because event-specific conditions such as the type of chemical, quantity of material, and release location will be critical to determining the appropriate course of action. Multiple attacks on the chemical infrastructure may not immediately be recognized as such. Prompt recognition that an incident is an actual case of terrorism and may be part of a series of attacks is critical to taking actions that may limit the consequences of such attacks. Recognizing that an attack is part of a larger coordinated effort may be hampered if incidents are widely dispersed, involve different types of attacks, or otherwise present challenges to recognizing a larger pattern, particularly if communication between affected parties is significantly impeded.

The perception of disasters among members of the public sometimes escalates as a consequence of a breakdown in the communication process. Conversely, a well-informed public can often take action to minimize the effects of a disaster. Information must reach the end users in a comprehensible and useful form; it must be perceived by them as relevant to their situation; and they must have the capacity and the necessary resources to use this information to better prepare for, respond to, and recover from a hazard or disaster situation. Research to determine the most critical information to be communicated between responders and to the public, and the means to gather and disseminate that information, can result in a rapid improvement in emergency response capabilities. Such research would be universally applicable to all chemical emergencies—independent of the type of incident or chemical involved.

RECOMMENDATION: DHS should explore ways to enable rapid analysis and communication of data for decision making and communication to the public during and after an emergency.

Near-term benefits can be obtained from research efforts directed toward enhancing emergency preparedness, emergency response, and disaster recovery. This offers an immediate means to mitigate the effects of a terrorist attack on the chemical infrastructure.

Through study of past events, social science research has derived significant understanding of the components required to prepare a community or a populace for hazardous events and to effectively respond to and recover from those events. Efforts to increase this knowledge and to expand its use in practice can rapidly enhance our capacity to mitigate the effects of a chemical event. This could, in turn, make the chemical infrastructure a less attractive target for terrorists. It has the further benefit that such efforts are "dual use"—of near or equal value in the case of a chemical accident.

RECOMMENDATION: DHS should support research directed toward enhancing emergency preparedness, emergency response, and disaster recovery.

SAFER CHEMISTRIES AND PROCESSES

The most desirable solution to preventing chemical releases is to reduce or eliminate the hazard where possible, not to control it. This can be achieved by modifying processes where possible to minimize the amount of hazardous material used, lower the temperatures and pressures required, replace a hazardous substance with a less hazardous substitute, or minimize the complexity of a chemical process.

Many of the advances required for development of practical alternatives to today's chemicals and chemical processes are fundamental and precompetitive. The economic incentives for industrial funding are frequently absent, which leads to the need for either a government investment in research or government-provided financial incentives for industrial investments. Inherently safer chemistry, such as process intensification, "just-in-time" chemical manufacturing, and the use of smaller-scale processes, offers the potential for improved safety at chemical facilities. While applications show promise and have found use within the chemical industry, these applications at present are still quite limited in scope.

RECOMMENDATION: DHS should support research and development to foster cost-effective, inherently safer chemistries and chemical processes.

The chemical sector is complex, with many links and interdependencies between operators. Economic research demonstrates that in an interdependent system, firms may have a disincentive to invest in security if all other operators in the system do not do likewise. Economic analysis of this sector and of the incentives and disincentives that firms have to take protective measures could help determine how some combination of regulation and private sector measures, such as insurance with third-party inspections, can be utilized to maximize firms' willingness to invest in appropriate security measures.

RECOMMENDATION: DHS should support research to determine the combinations of incentives and disincentives that would best encourage the private sector to invest in safety and security. This will require research to identify the nature of the interdependencies and weak links in the supply chain and consideration of public-private partnerships to encourage voluntary adoption of protective measures by the weakest links in the chain.

SAFETY AND SECURITY OF CHEMICAL STORAGE

A container holding significant quantities of a hazardous chemical provides an obvious terrorist target. Although efforts to strengthen existing containers against intentional rupture are ongoing, there may be opportunities to fundamentally change the means by which hazardous chemicals are stored. For example, methods to store chemicals in adsorbents are currently available but are generally limited to small quantities. Research could seek to enable the use of adsorbents at the cylinder scale and to use such storage methods for larger volumes involved in truck or rail shipments or on-site storage. Other possibilities for fundamental change in storage include low pressure storage (which would reduce the release rate given an unintended rupture) or underground storage technologies (which would reduce the storage tank profile presented to terrorists).

RECOMMENDATION: As a central element of a longer-term research program, DHS should seek ways to improve the safety and security of chemical storage in both fixed facilities and transportation.

IMPROVED DETECTION AND MONITORING

The near-term objective of enhancing emergency response effectiveness can be furthered through efforts to develop reliable detection techniques that can be distributed widely, are easy to use, and would give accurate results quickly and clearly. These can aid in "early warning" of chemical releases before they become catastrophic and would aid in decision making and response, prevention of catastrophic release, or more timely and effective emergency response. In research and development for chemical sensors, DHS should focus on furthering technologies that are relatively inexpensive to deploy and easy to use.

RECOMMENDATION: DHS should invest in S&T to enhance real-time monitoring of breaches in containment, the chemical infrastructure and any disruptions to it, and any resulting consequences of an event.

Using inventory controls as a means to quickly identify theft of hazardous chemicals may provide a fundamental means to prevent a terrorist attack. This capability may prove difficult if not impossible to mimic with sensor technology. Investments aimed at improving compliance with such procedures would be appropriate.

RECOMMENDATION: As it pursues sophisticated technologies for security monitoring, DHS should not neglect lower-technology solutions, such as inventory audits and inspections.

IMPROVED MODELS

Current disaster impact models have been generalized from natural disasters and accidents and may have features that do not apply in the case of a deliberate attack. Further research is needed to confirm that the models' assumptions and relationships are valid in these situations. Previous disaster research supports an all-hazards approach, in contrast to the focus on specific hazards that has emerged in recent approaches to homeland security. Furthermore, there is speculation, but little research, on whether human responses to intentional terrorist events differ significantly from responses to natural disasters or accidents. Such incongruities between current disaster models and current security concerns need to be identified and examined to determine what, if any, changes are required to our current understanding of mitigation planning, response, and recovery.

RECOMMENDATION: DHS should support research to extend the applicability of current disaster impact models to chemical events.

The presence and use of toxic chemicals create vulnerabilities and could result in catastrophic casualties. Effective predictive models of casualties could greatly reduce these vulnerabilities and improve emergency planning and response. Different levels of accuracy and precision are needed for different levels of emergency planning and emergency response. The accuracy and precision of situational models and consequence analysis currently in use must be better understood. Although the physics of a hazardous materials release can be described using models, effects on populations are not yet well characterized. Limitations in understanding the toxic effects of many substances and in understanding the dose-response relationship of hazardous chemicals over time, especially for vulnerable populations such as children, the elderly, and the poor limit current capacity to model casualties. Further efforts will be needed to understand the dispersion and toxicity of chemical mixtures. Furthermore, the reliance of early security risk assessments on the outputs of emergency planning efforts such as the Risk Management Plans submitted to Environmental Protection Agency has led to misimpressions of the potential consequences of individual events. While such data may have been useful for initial screening, they have also led to significant confusion and alarm among various decision makers and the public. Better and more appropriate data should be used, and clear explanations of the change should be provided to different stakeholders.

RECOMMENDATION: DHS should support the development and application of robust models to predict off-site consequences of chemical events and ensure that the type of model used is appropriate to the situation.

INTEGRATED RISK ASSESSMENT

While the consequences of a terrorist attack on the chemical infrastructure are of significance to the population affected, there is no reason to deviate from the principles and approach of good risk assessment and management decision making when prioritizing investments to mitigate these consequences. Each assessment should consider a realistic scenario and its vulnerabilities, likelihood of occurrence, and consequences if it were to occur. The scenario should be processed through a series of tests to assess if it can be significantly disruptive or catastrophic. These tests should consider loss of life, economic impact, and the ability of state and local governments to respond to the event, and should also consider the impact of social amplification. This should be followed by an analysis to assess the trade-off between expected benefit and cost of the proposed solution.

RECOMMENDATION: When considering investments to prevent or mitigate vulnerabilities, DHS should complete an overall risk assessment that would consist of analyzing the combination of vulnerability, threat or likelihood, and consequences of an event.

CONCLUSION

The findings and recommendations in this report emphasize the importance of the development of new technology and of investment in current technology and also highlight the need to combine this technology with effective communication strategies, reliable and effective mitigation techniques, and preparedness and response strategies. This combination is necessary to minimize the possibility of a terrorist attack and its effects or consequences.

When confronting the potential for terrorist attack, it is essential to constantly reassess both the progress being made and the possibility of unintended consequences when implementing a “solution.” The threat from terrorism is not static, and it is not unreasonable to assume that terrorist tactics will evolve with emerging technologies designed to defeat their threat. Some strategies to address terrorism reduce the chance of a successful attack, some reduce the consequences of such an incident, and some relocate the vulnerability—that is, these strategies may reduce the chance of direct casualties, but still leave financial and cascading impacts. All of these factors must be taken into consideration when assessing vulnerabilities of the chemical infrastructure.

1

Introduction

Since the attacks of September 11, 2001, federal, state, local, and tribal governments, aided by the private sector, have undertaken an unprecedented review of the nation's infrastructure to determine potential targets for future terrorist attacks. At the national level, the Department of Homeland Security (DHS) has divided the nation into 17 categories of critical infrastructures and key assets, one of which is the chemical industry and hazardous materials sector.[1] This study is intended to assist DHS in mitigating the vulnerabilities faced by the nation from this sector of the critical infrastructure.

Numerous studies have been and are being completed to understand the vulnerabilities posed by the sites, processes, and transportation meth-

[1]The other infrastructure categories are agriculture and food, water, public health and healthcare, emergency services, defense industrial base, telecommunication, energy, transportation, banking and finance, postal and shipping, national monuments and icons, dams, government facilities, commercial facilities, and nuclear reactors, materials, and waste. See the following for more information: (a) Office of Science and Technology Policy and U.S. Department of Homeland Security. 2004. *The National Plan for Research and Development in Support of Critical Infrastructure Protection*. Available at *http://www.dhs.gov/interweb/assetlibrary/ST_2004_NCIP_RD_PlanFINALApr05.pdf*; (b) U.S. Department of Homeland Security. 2005. *The Interim National Infrastructure Protection Plan*. Available at *http://www.deq.state.mi.us/documents/deq-wb-wws-interim-nipp.pdf.*

ods that make up the nation's chemical infrastructure.[2] These include DHS's Risk Analysis and Management for Critical Assets Protection (RAMCAP) exercise. RAMCAP describes an overall methodology and common framework for risk management that can be used to identify and prioritize critical infrastructure across all sectors. RAMCAP allows for comparable analysis and results within and between sectors. For the nation's chemical infrastructure, DHS is using RAMCAP to analyze specific chemical sites. The Environmental Protection Agency's (EPAs) Risk Management Plan (RMP) data represent a compilation of site-specific data submitted by the chemical industry in compliance with the Clean Air Act.[3]

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[2]Of the many efforts under way or recently completed on chemical infrastructure protection, some most relevant to the present study include the following: (a) American Chemistry Council. 2002. *Protecting a Nation: Homeland Defense and the Business of Chemistry.* Arlington, VA; (b) O'Hanlon, M., P.R. Orszag, I.H. Daadler, I.M. Destler, D. Gunter, R.E. Litan, and J. Steinberg. 2002. *Protecting the American Homeland: A Preliminary Analysis.* Washington, DC: Brookings Institution Press; (c) Tucker, J.B. 2002. "Chemical Terrorism: Assessing Threats and Responses." *High Impact Terrorism: Proceedings of a Russian-American Workshop.* Washington, DC: National Academy Press. 117; (d) Kleindorfer, P.R., J.C. Belke, M.R. Elliott, K. Lee, R.A. Lowe, and H.I. Feldman. 2003. "Accident epidemiology and the U.S. chemical industry: Accident history and worst-case data from RMP*Info" *Risk Analysis.* 23(5):865-881; (e) U.S. Department of Justice. 2000. *Assessment of the Increased Risk of Terrorist or Other Criminal Activity Associated with Posting Off-Site Consequence Analysis Information on the Internet.* Washington, DC: p. 13; (f) Congressional Research Service. 2003. *Chemical Plant Security.* RL31520. Washington, DC; (g) U.S. Department of Homeland Security. 2003. *The National Strategy for the Physical Protection of Critical Infrastructures and Key Assets.* Washington, DC; (h) U.S. Department of Homeland Security. 2005. *The Interim National Infrastructure Protection Plan.* Washington, DC; (i) U.S. Department of Homeland Security, Office for Domestic Preparedness. 2003. Vulnerability Assessment Methodologies Report: Phase I Final Report. Washington, DC; (j) American Petroleum Institute and the National Petrochemical and Refiners Association. 2004. *Security Vulnerability Assessment Methodology for the Petroleum and Petrochemical Industries.* Washington, DC; (k) National Institute of Justice. 2002. *A Method to Assess the Vulnerability of U.S. Chemical Facilities.* Washington, DC; (l) Center for Chemical Process Safety of the American Institute of Chemical Engineers. 2002. *Guidelines for Analyzing and Managing the Security Vulnerabilities of Fixed Chemical Sites.* New York, NY; (m) U.S. Department of Homeland Security. 2004. Capabilities Based Planning Overview. Available at *http://www.ojp.usdoj.gov/odp/docs/Capabilities_Based_Planning_Overview.pdf.*

[3]Because of lack of access to detailed information, the committee reviewed neither the accuracy nor the appropriateness of RMP data nor the merits of the RAMCAP methodology.

FOCUS OF THE STUDY

In discussions during the early portions of the study process that resulted in this report, DHS representatives made clear that they commissioned the report to complement their own RAMCAP exercise. Where RAMCAP is focused on a site-by-site analysis, this study attempts to take a systems-level view of the chemical infrastructure and the supply chain of which it is a part. Where RAMCAP is heavily focused on analyzing security measures within the chemical industry, this study is meant primarily to guide science and technology (S&T) investments by DHS that would reduce vulnerabilities associated with the chemical infrastructure. The full statement of task for this study is provided in Appendix B. How the statement of task was interpreted in light of discussions with DHS and based on available data is explained in the discussion that follows.

To clearly define the purview of this report requires the precise definitions of some words that might be used more loosely in common conversation:

- *Vulnerability* is the manifestation of the inherent states of the system (e.g., physical, technical, organizational, social, cultural) that can be exploited by an adversary to adversely affect (cause harm or damage to) that system.
- *Intent* is the desire or motivation of an adversary to attack a target and cause adverse effects.
- *Capability* is the ability and capacity to attack a target and cause adverse effects.
- *Threat* is the *intent* and *capability* to adversely affect (cause harm or damage to) the system by adversely changing its states.
- *Risk* is the result of a threat with adverse effects to a vulnerable system.[4]

This report is concerned with the vulnerabilities that the nation faces from its chemical infrastructure. Vulnerabilities are determined by the inherent states of a *system*. These vulnerabilities arise not only from character-

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[4]Haimes, Y.Y. 2004 *Risk Modeling, Assessment, and Management,* 2nd Edition. New York: John Wiley & Sons. p. 699. Definitions presented here may differ from those used in the U.S. Department of Homeland Security National Infrastructure Protection Plan.

istics of the chemical infrastructure itself, but also from characteristics of the system within which that infrastructure operates—for example, the local environment (e.g., communities, population size, natural resources) surrounding a plant, pipeline, or transportation channel; the economic dependencies between the chemical facility and other producers and users both upstream and downstream in the supply chain; and the organization and structure of local, state, and national regulatory and response capabilities.

This study was not intended to address the intent and capabilities of any potential adversary, nor was information on the intent and capability of any potential adversary available for the study. Therefore, this report does not discuss threat or risk as defined above.

Another way to understand the purview of this report is to consider risk assessment as an attempt to answer the following three questions:

1. What can go wrong?
2. What is the likelihood that it will go wrong?
3. What are the consequences?[5]

This report considers questions 1 and 3, which can be discussed at least qualitatively and sometimes quantitatively based on a wide range of open-source information. Consistent with the statement of task, which refers to "terrorist attack and other catastrophic loss," this report concerns itself with consequences that reach catastrophic levels of casualties or catastrophic damage to the national economy.[6] The report does not consider question

[5](a) Kaplan, S., and J.B. Garrick. 1981. On the quantitative definition of risk. *Risk Analysis* 1(1):11-27; (b) National Research Council. 2002. *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism.* Washington, DC: The National Academies Press. pp. 306-308.

[6]"Catastrophic Incident— Any natural or manmade incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions. A catastrophic event could result in sustained national impacts over a prolonged period of time; almost immediately exceed private-sector authorities in the impacted area; and significantly interrupt governmental operations and emergency services to such an extent that national security could be threatened. All catastrophic incidents are Incidents of National Significance." The Department of Homeland Security uses the following planning assumption in terms of catastrophic casualties: "A catastrophic incident results in large numbers of casualties and/or displaced persons, possibly in the tens of thousands." Department of Homeland Security National Response Plan, December 2004.

2, which would require intelligence information that was not available and analysis of terrorist networks and their capabilities, which was not considered part of this task.

Once the three questions above have been addressed, one asks what can be done to prevent the undesired event and to mitigate, respond to, and recover from its consequences. In the language of risk modelers, the risk assessment is followed by risk management. Risk management seeks to answer a second set of questions:

1. What can be done and what options are available?
2. What are the trade-offs in terms of all costs, benefits, and risks?
3. What are the impacts of current management decisions on future options?[7]

This report was chartered to provide DHS with guidance in making science and technology investments, especially research investments, aimed at protecting the nation from risk or hazard due to its chemical infrastructure. Because of this, the report focuses on answering the first of these three questions and provides limited comments on the other two.

When discussing "science and technology investments," this report refers to investment in research in the physical, medical, social, and engineering sciences to develop the fundamental knowledge needed to better secure the nation from vulnerabilities resulting from its chemical infrastructure; in development efforts to take basic research results and move them toward applicability; or in development efforts designed to take an application currently in use in one sector and adapt it to the needs arising from the chemical infrastructure. This report does not concern itself with technology evaluation or procurement.

COMMITTEE APPROACH

To address the statement of task as discussed above, an analysis of the chemical infrastructure was used to identify its potential vulnerabilities. First, categorization of all the chemicals encompassed by the chemical infrastructure and a description of the chemical supply chain were devel-

[7]Kaplan, S., and J.B. Garrick. 1981, On the quantitative definition of risk. *Risk Analysis* 1(1):11-27.

oped. An examination of the general categories of chemicals and the chemical supply chain characteristics (Chapter 2) led to the identification of vulnerabilities (Chapter 3). A red teaming type exercise was then completed to determine ways in which the identified vulnerabilities could be exploited. All possibilities envisioned in this exercise were variations or combinations of a limited number of cases that required further examination. To demonstrate the adequacy, application, and plausibility of these cases and their potential consequences, general, illustrative scenarios were developed (Chapter 4). These scenarios utilized historical examples to illustrate the plausibility of the cases identified and their vulnerabilities, and to provide an existence proof of the possible consequences of not mitigating these vulnerabilities. Consideration of the scenarios and their consequences, and a detailed discussion of emergency management and risk mitigation (Chapter 5), led to the development of both general and specific science and technology recommendations created to guide DHS S&T initiatives (Chapter 6).

2

The Chemical Sector

The products of the chemical industry are ubiquitous in modern life. Plastics, fibers, drugs—these are a few of the products we encounter everyday in our workplaces and homes that are direct products of the chemical industry. Many more of the products we use daily—paper, fabrics, cosmetics, and electronics—are produced using the products of the chemical industry. The chemical sector is a key part of the national economy: while its products represent only 2 percent of the U.S. gross domestic product,[1] they underpin most other manufactured goods and enable our way of life.

The chemical sector is diverse and wide-ranging. It includes firms that manufacture huge volumes of chemicals intended for many uses—such as major refineries processing thousands of tons of petrochemical feedstocks daily—and firms that produce small quantities of materials with highly specific uses, such as small pharmaceutical companies producing products in gram or kilogram quantities after many days of processing and purifying. The facilities in which chemicals are produced are similarly varied—from refineries covering square miles of land with many high-volume chemicals on-site, to startup companies occupying thousands of square feet in light

[1]American Chemistry Council. 2004. *Guide to the Business of Chemistry*. Washington, DC. p. 6.

industrial parks. Products can be transported to their final place of use by truck, rail, pipeline, or other means in both large and small quantities.

To identify the vulnerabilities posed to the nation to terrorist attack on or other catastrophic loss in the nation's chemical infrastructure, it is necessary first to somehow succinctly characterize this large and varied sector. This is done below in two steps: (1) a scheme for categorizing the vast number of chemicals produced by the sector and defining these categories and (2) a general model describing the sector's supply chain.

CHEMICAL CATEGORIES

Virtually all chemical manufacturing, storage, and use in the United States fits into one of the following categories:

- Petrochemicals and fossil fuels
- Inorganic chemicals including fertilizers
- Industrial gases
- Specialty chemicals
- Pharmaceuticals
- Consumer products.[2]

A description of each of these categories, including a generalized discussion of the manufacture, transport, and use of the chemicals within that category, is given below:

Petrochemicals and Fossil Fuels

This category entails chemicals produced from hydrocarbon feedstocks, such as crude oil products and natural gas. It includes such chemicals as hydrocarbons and industrial chemicals (e.g., alcohols, acrylates, acetates), aromatics (e.g., benzene, toluene, xylenes), and olefins (e.g., ethylene, propylene, butadiene, methanol).

Manufacture and Use. Most of these chemicals are produced and sold in large volumes—so-called commodity chemicals—and most can be pro-

[2]These categories are a simplified version of the categorization used by the American Chemistry Council (ACC) in its yearly economic analysis of the industry. See American Chemistry Council. 2004. *Guide to the Business of Chemistry.* Washington, DC.

duced through several different chemical routes or processes. They are used as building blocks in many manufactured products. Many of these chemicals can be replaced by another, with only minor modification required to the user's manufacturing process and with only minor changes in the performance of the final manufactured product.

Hazard. Most of the products, intermediates, and by-products in this category are highly flammable, and some are toxic (e.g., hydrogen cyanide, hydrogen sulfide, phosgene). Some can form explosive vapor clouds upon release.

Locations of Production. A large percentage of manufacturing facilities for petrochemicals and fossil fuels are located along the Texas and Louisiana Gulf Coast, but significant installations are also found in the industrial areas of the East Coast, Midwest, and California.

Location of Storage and Usage. Nationwide.

Distribution. Refinery products and a number of petrochemicals (e.g., ethylene, naphtha, ethylene oxide, benzene) are transported to other plants via pipeline, barge, rail, or truck for further processing.

Inorganic Chemicals and Fertilizers

This category includes acids (e.g., sulfuric, nitric) and alkalis (e.g., caustic soda, soda ash), chlorine, ammonia, and ammonia-derived fertilizers. It also includes fluorine derivatives (e.g., hydrogen fluoride), phosphates, potash, pigments (e.g., titanium dioxide), and certain metals such as mercury.

Manufacture and Use. Many of these chemicals, such as chlorine, ammonia, and ammonia-derived fertilizers, are produced and purchased in large volumes as commodity chemicals and may rely on natural gas or crude oil as a feedstock. They are used both as building blocks for other manufactured goods and as end products in themselves (e.g., chlorine, ammonia-derived fertilizers). The chemicals in this category can be substitutable, although not always readily; for example, substances other than chlorine gas can be used to purify drinking water, but at a cost of time and money to effect the substitution that may not be acceptable to all communities.

Hazards. While many of products in this category are nontoxic and relatively unreactive such as potash and pigments, hazards found in this category include corrosives such as acids and fluorine derivatives and toxics such as chlorine, alkalis, ammonias, and heavy metals.

Location of Production. Inorganic chemicals are produced in many parts of the United States, but largely in the South and Midwest.

Location of Storage and Use. Fertilizers are stored and used throughout agricultural areas. Other products tend to be stored and used near manufacturing sites. Chlorine is often found stored in or near petrochemical plants where it is produced and stored in large quantities. Chlorine can also be stored in or near water treatment facilities. Other inorganic chemicals are used in mining and many other industries throughout the country.

Distribution. Chemicals in this category are transported to other plants or to end users via pipeline, barge, rail, or truck. Some facilities are able to generate some of these chemicals on-site on an as-needed basis in order to avoid transport and storage.

Industrial Gases

This category encompasses two general classes: (1) gases used primarily in large quantities as auxiliaries in other manufacturing processes (e.g., refining, petrochemical or steel manufacture), including nitrogen, oxygen, hydrogen, and carbon monoxide, and (2) specialty gases that are produced in smaller quantities to serve the electronics, food, and other industries.

Hazards. Hazards are dependent on the chemical under consideration and the quantity in which it is being used. For instance, nitrogen is a chemical asphyxiant that displaces oxygen at high concentrations, oxygen promotes combustion, hydrogen is flammable, and carbon monoxide is a simple asphyxiant that binds more strongly than oxygen to hemoglobin and is also flammable. Hazards from specialty gases are due typically to toxic, irritant, or asphyxiant properties.

Manufacture and Use. These gases are produced by multiple firms in both large and small facilities.

Location of Production. The first class of industrial gases is produced in large plants, often adjacent to large users, such as refineries on the Gulf Coast. Specialty gas manufacture is more distributed and occurs in smaller facilities.

Location of Storage and Use. High-volume gases can be manufactured at or adjacent to the point of use and are usually stored as liquids in specially designed cryogenic tanks. Both classes are stored in smaller quantities in gas cylinders.

Distribution. High-volume chemicals can be distributed via pipeline or as cryogenic liquids in railcars or tank trucks. Cylinder-sized volumes are transported by rail or truck.

Specialty Chemicals

This category comprises a large number of chemicals that are used as aids to the manufacture of other major products (e.g., in paper milling, plastics production, water treatment, mining), are used as end products (e.g., pesticides in farming), or are components of consumer products (personal care products, paints and coatings, adhesives and sealants, photographic chemicals).

Manufacture and Use. Most chemicals in this category are produced and sold in relatively small quantities (grams to hundreds of kilograms). Unlike the categories discussed above, specialty chemicals often have a single manufacturer. Their use is highly specific, but if some deviation in final product performance can be tolerated, most are substitutable.

Hazards. Some specialty chemicals are toxic.

Location of Production. Diversified.

Location of Storage and Use. Diversified.

Distribution. Chemicals in this category are produced in either continuous or batch (smaller, noncontinuous) plants and are shipped to users in 55-gallon drums or smaller containers.

Pharmaceuticals

This category includes prescription and over-the-counter drugs, diagnostic substances, vaccines, vitamins, and preparations for both human and veterinary uses.

Manufacture and Use. The large majority of pharmaceuticals have multiple manufacturers; most have available substitutions. A notable exception, however, is vaccines, which tend to have one or two suppliers and may have no substitutions.

Hazards. The production processes used are similar to those in large chemical plants, but pharmaceuticals are produced in much smaller quantities and with much more stringent quality control. The production of pharmaceuticals can entail the generation of combustible dust as well as use of toxic industrial chemicals in relatively small quantities.

Location of Production. Diversified.

Location of Storage and Use. Pharmaceuticals are warehoused in prepackaged units until distributed to end users.

Distribution. Pharmaceutical manufacturing includes the production of pills or other end-products that are then packaged and sent to distributors and pharmacies.

Consumer Products

This category entails formulated products, such as soaps, detergents, bleaches, paints, solvents, glues, toothpaste, shampoos, cosmetics, skin care products, perfumes, and colognes intended for direct consumer use.

Manufacture and Use. Although each product within this category is somewhat differentiated from its competitors, all are readily substitutable with products from multiple manufacturers.

Hazards. The contents of consumer products may be toxic, corrosive, or flammable; many have quick skin-bonding characteristics; or their packaging may be pressurized.[3] Consumer products can be particularly vulnerable to tampering since their distribution is widespread and under relatively loose control at the retail level.

Location of Production. Nationwide.

Location of Storage and Use. These products are used widely and are commonly found in households and retail outlets nationwide.

Distribution. All of these items are available to the general public and are sold in packaged form in retail stores, by mail order, and on-line.

THE CHEMICAL SUPPLY CHAIN

The description of the chemical categories above includes some specific characteristics of feedstocks, manufacturing, storage, and use for each. From these specifics it is possible and instructive to draw some generalizations about the chemical supply chain. Here that supply chain is presented as a network using a model described by the characteristics of the materials and infrastructure involved; the pathways, links, and nodes between manufacturers and users; and the ownership and control of the components. The model as described applies to most of the chemical industry. Exceptions to the model are noted where relevant. The main characteristics of the network follow.

Materials

The chemical industry is materials intensive. Most chemical products can be produced from a variety of starting materials, although many of

[3]See the following web site for more information: Consumer Product Safety Programme, available at *http://www.hc-sc.gc.ca/hecs-sesc/cps/*.

those starting materials are dependent upon crude oil or natural gas as a feedstock. The supply network for these starting materials tends to be diversified: in general, a single supplier does not provide all of the starting materials for a final manufactured chemical product. Suppliers of materials may be domestic or international.

Infrastructure

The chemical industry is highly capital intensive, requiring substantial facility and equipment investment. Many chemical facilities contain specialized equipment that, if destroyed, would be difficult to replace quickly (e.g., cracking facilities). Most chemical manufacture requires a small number of personnel per square foot of facility. For example, a large petrochemical refinery with a footprint of several square miles may have only a few hundred employees on-site under normal circumstances.

Pathways, Links, and Nodes

The supply chain for any chemical is characterized by multiple nodes, links, and pathways. A node is a facility at which the chemical is produced, stored, or consumed; a link is the means (road, rail, barge, or pipeline) by which the chemical is transported from one node to another; and a pathway is the sequence of nodes and links by which the chemical is produced, transported, and transformed from its initial source to its ultimate consumer. Dominant nodes are geographic locations in which a substantial proportion of a chemical is concentrated—possibly because of a small number of facilities with large capacities or a large number of facilities with small capacities. Dominant links are similarly defined as links over which a substantial proportion of a chemical is concentrated during its passage through the supply chain. Pathways and links exist in the transfer of materials between facilities, companies, and sectors. Transfer of materials requires transport, usually via rail, road, ship, or pipeline between plants.

The chemical supply chain also has dominant nodes—small geographic areas where large concentrations of products or intermediaries exist, (e.g., the Gulf Coast) or connecting points (dominant links) where many diverse streams in the supply chain converge, (e.g., a pipeline, large natural gas or ethylene storage terminals). Although the industry as a whole is geographically dispersed, some sectors of the chemical industry are geographically clustered (e.g., petrochemicals in the Gulf Coast), thereby creating a dominant node.

A highly complex and distributed supply chain makes it difficult to shut down the entire system by interruption at a single point. However, determining if an attack at a dominant node or a dominant link of the supply chain of a critical chemical would bring production to a standstill is a high priority in determining overall vulnerability. In order to achieve a widespread interruption in production for an extended period, multiple, well-placed interruptions would have to occur at one or more dominant nodes or dominant links (or both)—in most cases, at multiple geographic locations.

Ownership and Control

Most of the chemical infrastructure is under private ownership with the exception of certain feedstocks (e.g., oil reserves). Although most chemical companies in the United States are domestically owned, a number of companies are based in other countries with sites in the United States. Most large chemical companies have multiple sites or locations domestically and globally, which allows for highly decentralized ownership and control of the supply chain. Removing a single node or link is not sufficient to disrupt the entire supply chain for a given chemical. However, lack of centralized control may hinder a timely response to a terrorist incident or to a series of terrorist incidents.

At the plant level, many control systems are automated. Because of safety concerns, manufacturers give high priority to ensuring that automation does not exacerbate an emergency. The supervisory control and data acquisition (SCADA) system software is designed to shut down a process when it exceeds safe operating parameters, but it is not the primary safety system in a well-designed chemical production facility. Good process design in the chemical industry also includes safety shutdowns that are independent of the SCADA system. Plants conforming to standards ISA 584.01, International Electrotechnical Commission (IEC) 61508, and IEC 61511 are less vulnerable to catastrophic release due to attack through the SCADA system than those that are not compliant, unless these independent safety shutdown systems—either hard-wired or independent automated systems with no remote access to the outside world— have also been altered. Thus, effecting a release or other disruption through the automated control system requires not only reprogramming the SCADA software, but also physically infiltrating the site and systematically disabling these other fail-safe mechanisms.[4] However, sabotage of an automated process remains a possibility, and the controls in place to mitigate the effects of an accident may not be adequate when intentional disruption or destruction occurs if the standards cited above have not been conformed to or if fail-safe mechanisms have not been properly maintained.[5]

Robustness of the Supply Chain

Since the products of the chemical sector play such an important, underpinning role in our modern life and the national economy, the economic effects of a disruption to this supply chain must be considered seriously.

Unlike many other sectors that are considered part of the nation's critical infrastructure, such as utilities, the chemical sector has more than 200 years of experience operating in the free market. Strong competition has ensured that manufacturers have contingency plans in place to meet customer demands in the event of a disruption to their manufacturing capacity. These include product stockpiles, plans to shift manufacturing to other locations, plans to assist customers in shifting their processes temporarily to similar but alternative products, and in the case of large-scale interruption of manufacturing capacity, cooperative agreements between competitors during emergencies to ensure that critical needs for a given chemical can be met. In many cases, customers can simply acquire supplies from domestic and international competitors of their suppliers to fill their need. In cases where a specialty chemical with one or a few suppliers is disrupted, customers can be shifted temporarily to alternative chemicals, which may come at the price of slightly higher production cost or slightly altered product characteristics, but are generally within acceptable standards. To have a cata-

[4]This essentially requires an insider attack, which argues not for better SCADA or fail-safe systems, but for the importance of employee background checks, and explains why some industry officials would like the capacity to cross-check potential hires against terrorist watch lists.

[5]National Research Council. 2002. *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*. Washington, DC: The National Academies Press. Chapters 5 and 11 of this report discuss SCADA systems, although they do not discuss their specific use in the chemical industry.

strophic national economic impact or result in catastrophic casualties, the chemical or chemicals whose supply is disrupted would have to (1) be critical to a large portion of the economy or to public health; (2) have a production process that is not readily restarted in a short period of time; (3) be unsubstitutable; and (4) be intended for an end use for which there is no other substitute. In other words, both the chemical itself and the product in which it is ultimately used would have to be unsubstitutable by some other chemical, product, or method of achieving the final end within the period required to drain whatever stockpile of the chemical or product exists. The competitive marketplace in which the chemical sector exists works against such a possibility, at least in the case of civilian products and uses.[6]

Examination of the historical record backs up these assertions. For example, in 1999 two of the three plants worldwide capable of producing hydroxylamine, a key component of specialty chemicals used in semiconductor fabrication, suffered catastrophic explosions and ceased production. In response, chemical firms doing significant business with electronics manufacturers directed their customers to hydroxylamine-free products and processes until hydroxylamine capacity was restored. Although the substitution raised costs for semiconductor manufacturers slightly, fabrication did not suffer a significant disruption. Hurricanes, most recently Hurricane Katrina, have shut down significant portions of the nation's petroleum and natural gas supply (key feedstocks to the chemical industry), with subsequent economic loss but without catastrophic economic consequences. By the end of 2005, some four months after Hurricane Katrina hit, approximately 25 percent of petroleum and 20 percent of natural gas capacity from the Gulf of Mexico remained "shut in," down from roughly 50 percent in the weeks after the storm.[7] The full extent of economic consequences from the disruption to supply remains to be seen as of this writing and will require evaluation in the years to come; the nation has seen higher gasoline and heating costs, and costs of consumer goods are expected to reflect these increased energy prices. Even with this, however, economic consequences *from the disruption to the chemical infrastructure* (though not from the hurricane overall) have been notable but not catastrophic to date. Katrina pro-

[6]The Department of Defense (DOD) tracks the supply of key materials for military purposes. The committee did not have access to the DOD analysis.

[7]From information provided on the U.S. Department of Energy web site. *http://tonto.eia.doe.gov/oog/special/eia1_katrina.html.*

vides other examples of how the chemical infrastructure responds to disruption. For example, cooperative agreements between liquid hydrogen producers were activated to ensure that strategic needs for this cryogenic material were met. Even the worst accidents on record (Bhopal, Toulouse, Texas City) did not result in a situation in which the supply of the chemical or fertilizer in question could not be made available in a short time.

Agricultural chemicals and pharmaceuticals are the areas most likely to be impacted by single suppliers of specialty chemicals. However, major herbicides and fungicides have alternatives that perform as well or almost as well, so that normal agricultural practice can continue should the supply of preferred product be disrupted.[8] Likewise, pharmaceutical manufacturers typically stockpile two to three months' supply of their products as a contingency against disruption of their manufacturing capacity. Should a disruption occur that cannot be rectified in that period, doctors have two to three months to migrate their patients to alternative drugs and treatment, which exist for every major category of pharmaceutical on the market. The exception is organism-specific pharmaceuticals, such as vaccines, for which a substitute may not exist.

[8]The U.S. Department of Homeland Security should confirm whether multiple products are available for use against pathogens of concern for potential agricultural bioterrorism attack. See National Research Council. 2003. *Countering Agricultural Bioterrorism.* Washington, DC: The National Academies Press.

3

Methodological Approach to Determining Vulnerabilities

Vulnerabilities associated with the chemical infrastructure arise from the properties of chemicals, the properties of the chemical supply chain, and the environment within which the infrastructure and supply chain exist. The consequences from a deliberate exploitation of one or more of these vulnerabilities can be further magnified or dampened by public or societal response to the event. The description of the chemical categories, the generalized model of the chemical supply chain, and a consideration of environmental and social factors lead to a series of questions that can be used to identify those vulnerabilities that are of potentially catastrophic consequences.

CHEMICAL PROPERTIES OF CONCERN

Casualties are most readily caused by exploiting the toxic, explosive, or flammable properties of chemicals. By far the largest number of casualties would be anticipated from situations involving toxic inhalation hazards, that is, large-scale release of toxic chemicals in a gaseous form. For example, hazard estimates by staff of the U.S. Environmental Protection Agency's (EPA's) Chemical Emergency Preparedness and Prevention Office for a worst-case accident involving a flammable substance give a median population within the vulnerable zone[1] of 15, and for toxic inhalation risk give a

[1]The area of the vulnerable zone impacted by an actual event depends upon the quantity and toxicity of the chemical released, as well as meteorological conditions such as wind

median population within the vulnerable zone of 1,500.[2] Damage to infrastructure and subsequent economic loss are more readily caused by the flammable and explosive properties of chemicals.

Some chemicals are significantly more hazardous than others. For example, it is possible to rank chemicals with toxic inhalation properties according to toxicity, by using, for example, the Department of Transportation Hazmat Tables, which list toxicities according to LD_{50}.[3] A compound such as methyl isocyanate has a much lower LD_{50} (i.e. is significantly more toxic) than, for example, chlorine. Properties of the specific chemicals involved are important to first responders attempting to mitigate a specific incident to prevent a catastrophic result. However, this report is concerned with identifying research and development that will help prevent any incident from crossing the threshold of catastrophic impact. Depending on actual event circumstances, which include many factors other than toxicity, chlorine can be of equal or of more concern than methyl isocyanate. As a result, above a certain threshold, the relative toxicity (or flammability or explosivity) of two chemical species becomes less relevant.

Whatever the specific chemical involved, all releases progress through a similar series of stages (e.g., release, transport, diffusion, exposure). The release consequences will be affected by the source (e.g., release rate, release duration, and toxicity), meteorology (wind speed, wind direction, atmospheric stability, precipitation), and population (e.g., population distribution and structural protection; response action) factors. Similar opportunities for emergency response and similar consequences (casualties, property damage, and environmental insult) are possible. This provides the opportunity for investments in science and technology development that mitigate

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speed and direction. The exposed area is likely to be only 25 percent (one quadrant) of the total vulnerable zone at most, and probably less. The number of people exposed in such an event depends on the size of the impact area and the size of the population remaining in that area. This might be only a small fraction of the total number of people living in the vulnerable zone, especially if they are able to take prompt protective action such as evacuation or sheltering in-place.

[2]Belke, J. 2001. Chemical accident risks in US Industry—A preliminary analysis of accident risk data from US hazardous chemical facilities. *Proceedings of the 10th International Symposium on Loss Prevention and Safety Promotion in the Process Industries.* Stockholm, Sweden: Elsevier Sciences.

[3]Lethal dose 50 (LD_{50}) is the dose at which 50 percent of an exposed animal model population dies.

against all risks in this hazard category. Continuing with the above example, highly toxic chemicals have the potential to cause thousands of casualties with a single release under the worst circumstances. DHS therefore could make investments in science and technology development that are specific to the methyl isocyanate risk, or it can make investments that mitigate the methyl isocyanate risk while also reducing risks from other highly toxic materials. In the absence of specific threat information, it will be most appropriate at this time for DHS to invest its research efforts, including technology development, for general classes of vulnerabilities.

In the case of either casualties or economic loss, catastrophic levels of consequences are expected only where large quantities of chemicals with these properties are involved. However, social response may amplify the effects of an incident involving even small quantity of chemicals to the point where its economic effects, not its casualties, become catastrophic or at least of national concern.

SUPPLY CHAIN CHARACTERISTICS OF CONCERN

The model of the chemical supply chain presented in Chapter 2—which considers materials, infrastructure, pathways, links and nodes, and ownership and control of the network—leads to characteristics that, if present in any given case, could pose vulnerabilities. These characteristics include the following:

- Key materials without obvious substitutions;
- Single suppliers of key materials with no potential alternative source;
- A plant or production process that uses high volumes of toxic, flammable, or explosive materials;
- Dominant nodes or dominant paths between nodes;
- Vulnerable points of control where theft of or tampering with a chemical can occur; and
- Interdependencies in the supply chain.

SITING CONCERNS

The consequences of an event at a chemical plant or storage facility can be greater or lesser depending upon the local environment in which the facility exists. If a facility is located within a major population center, the number of potential casualties increases. If the facility is near a major transportation corridor, disruption of that corridor and subsequent economic loss become possible. If the facility is near important public infrastructure, such as a water supply, potential consequences increase.

SOCIETAL RESPONSE

Societal response has the potential to transform the consequences of an event by either diminishing or amplifying them. For example, in the event of a hazardous material release, a community whose residents know how to shelter in-place and do so when instructed may suffer many fewer casualties than another community whose residents are not so prepared. Conversely, negative reaction can amplify the consequences of an event. One example of magnification is the loss of business faced by airlines in the weeks and even months after the September 11, 2001, events—many people refused to fly even though, arguably, flying was safer after that date with the implementation of new security rules. Amplification is most likely to affect economic consequences rather than casualties since, contrary to popular belief, people rarely panic in the face of disasters.[4] Societal response and emergency planning are discussed in more detail in Chapter 5.[5]

PRIMARY ANALYSIS OF VULNERABILITIES

Using the six categories of chemicals discussed in Chapter 2 and the supply chain characteristics and chemical properties of concern, it is possible to construct a matrix representing the primary vulnerabilities posed within each category (Figure 3.1). This matrix is not meant to be exhaustive; rather it is meant to represent those combinations of supply chain characteristics and chemical properties that could lead to catastrophic consequences. The number of boxes checked does not necessarily indicate that any one class of chemicals is inherently more or less vulnerable. The checked boxes identify the highest areas of priority in each chemical category that can be utilized to guide investment intended to mitigate vulnerability.

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[4]Clarke, Lee. 2002. Panic, myth or reality? *Contexts* 1(3):21-26.

[5]See also National Research Council. 2002. *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism.* Washington, DC: The National Academies Press. pp. 270-275.

CHEMICAL CATEGORIES

SUPPLY CHAIN CHARACTERISTIC	Inorganic Chemicals	Pharmaceuticals	Industrial Gases	Specialty Chemicals	Consumer Products	Petrochemicals and Fossil Fuels
Single Supplier/Limited Production		X				
Long Replacement Time		X				
Lack of Substitution	X			X		X
Siting Concerns	X		X	X		X
High-Volume Materials	X		X			X
Dominant Node or Path Between Nodes/Transportation	X		X			X
Lack of Control	X		X	X	X	X

FIGURE 3.1 Primary vulnerabilities by chemical category.

A red teaming type exercise determined situations in which their exploitation could lead to catastrophic consequences.

Another way of presenting this information is given in Figures 3.2-3.4. These figures make it clear that the primary cases of concern can be narrowed to three general cases with potential catastrophic consequences:

1. Key materials (shortage) (Figure 3.2)
2. High-volume toxic, flammable, and explosive chemicals (Figure 3.3)
3. Vulnerable points of control (theft or tampering) (Figure 3.4)

The aspects of nodes and interdependencies as vulnerabilities of the chemical infrastructure are depicted in the vulnerable points of control flowchart (Figure 3.4). These are the only vulnerabilities in the flowcharts that are not discussed as a scenario in the next chapter. No single vulnerable node within the chemical supply chain was identified that if disrupted, would lead to catastrophic consequences. Targeting of multiple nodes is required to have catastrophic consequences. Similarly, the interdependencies that were identified were not of a high level of concern. Previous analysis based on records of terrorist attacks against the chemical infrastructure reached a similar conclusion:

> To do significant damage that truly impacts the U.S. critical infrastructure—rather than inflicting symbolic damage or causing large numbers of casualties—would require the large-scale targeting of select facilities, especially those that are key manufacturers of critical chemicals or single producers of raw chemicals. Most potentially catastrophic for the U.S. chemical critical infrastructure would be a coordinated attack on a number of facilities responsible for key precursors, the disruption of which would cause a bottleneck blockage. Fortunately, the selection of such facilities would require sophisticated knowledge of chemical manufacturers, industrial processes, distribution, and warehousing. It would also require a substantial effort by a relatively large, well-financed terrorist group with access to individuals with specific scientific or technical knowledge.[6]

Although there are other vulnerabilities, only the three cases identified above clearly have the potential for catastrophic consequences. These cases are examined further in illustrative scenarios in Chapter 4. The scenarios are used to test and illustrate the conclusions and observations derived from the analysis.

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[6]Monterey Institute of International Studies Center for Nonproliferation Studies. 2004. *Assessing Terrorist Motivations for Attacking Critical "Chemical" Infrastructure*. Monterey, CA. p. x.

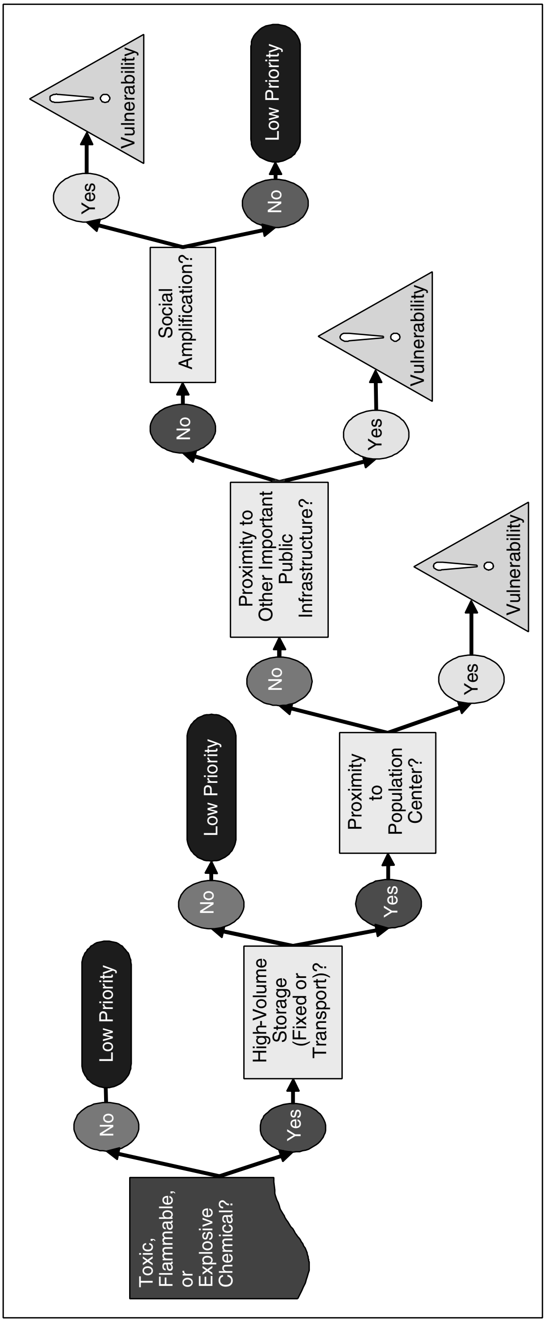

FIGURE 3.2 Flowchart leading to a high-volume storage scenario.

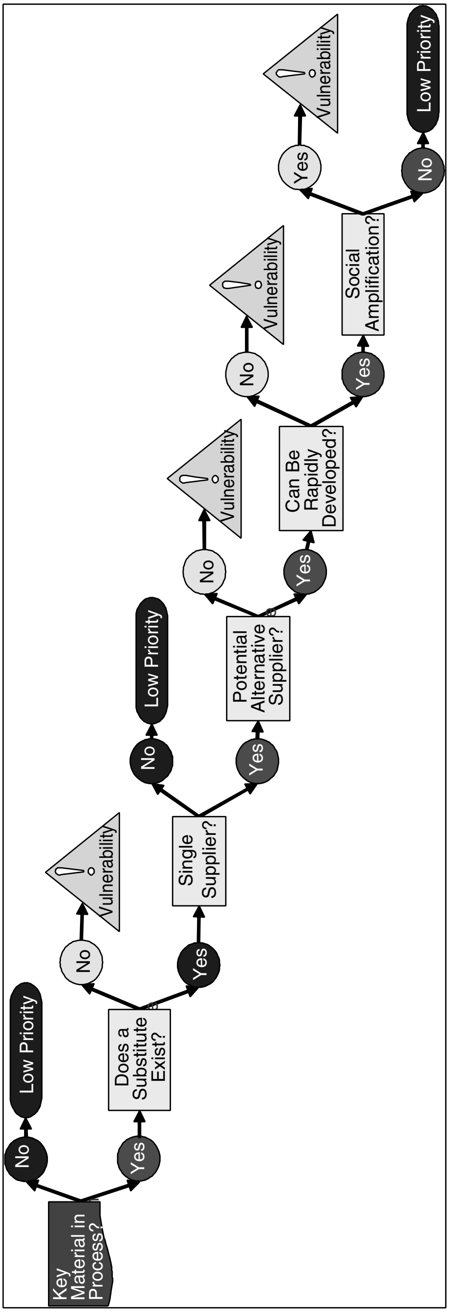

FIGURE 3.3 Flowchart leading to a shortage scenario.

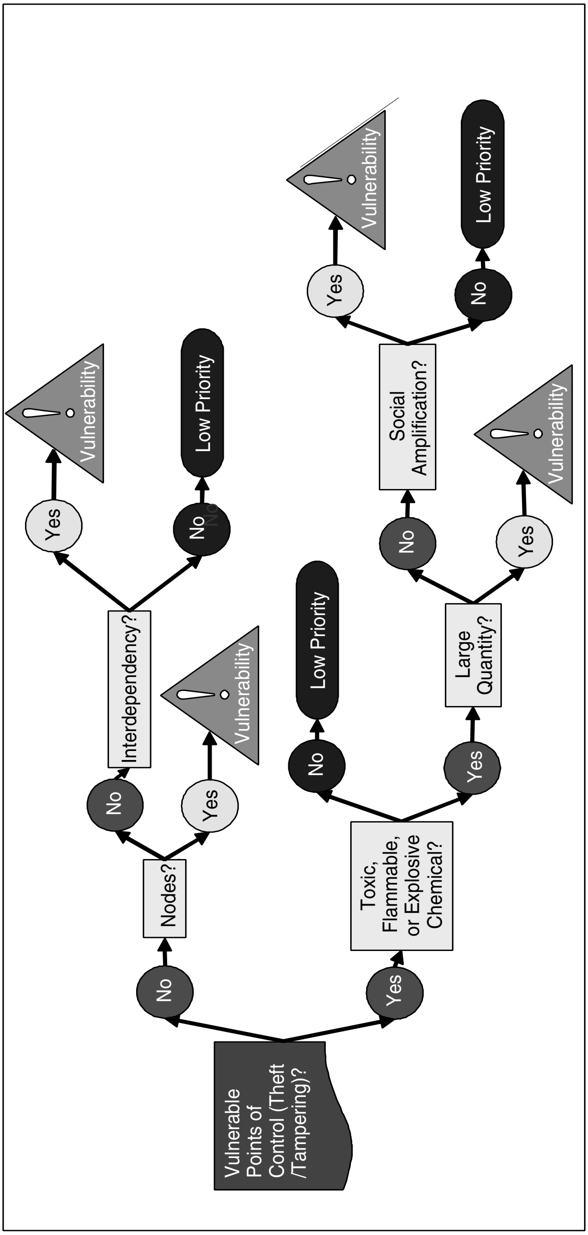

FIGURE 3.4 Flowchart leading to a misuse scenario.

4

Realistic Chemical Incident Scenarios

Open-source information about the chemical industry, information provided through briefings during the course of this study, and the knowledge and experience of the members of the authoring committee were analyzed using the methodology of Figure 3.1 to envision potential scenarios with catastrophic consequences. Scenarios that would not lead to levels of consequence considered "catastrophic" were discarded. All possible scenarios envisioned that resulted in catastrophic consequences were versions of one of three basic scenarios: high-volume release (fixed site or transport), shortage, and misuse (i.e., theft or tampering). Figures 3.2-3.4 map how the characteristics discussed in Chapter 3 were applied to reach this conclusion.

Because the charge for this study calls for identification of federal science and technology (S&T) investments that could prevent or mitigate these consequences, for each scenario the following questions were also considered:

- Would investment in S&T help mitigate or reduce the consequences of this scenario? In particular, can S&T solutions be proposed that can help prevent the event from rising to the level of catastrophic?
- Is there a federal role in the investments?

THE FEDERAL ROLE

Homeland Security Presidential Directive (HSPD)-7[1] establishes a national policy for federal departments to identify and prioritize the critical infrastructure and key resources of the United States, and to protect them from terrorist attacks. It directs federal agencies to enhance the protection of our Nation's critical infrastructure and key resources against terrorist acts that could:

> (a) Cause catastrophic health effects or mass casualties[2] comparable to those from the use of a weapon of mass destruction;
> (b) Impair federal departments' and agencies' abilities to perform essential missions, or to ensure the public's health and safety;
> (c) Undermine state and local government capacities to maintain order and to deliver minimum essential public services;
> (d) Damage the private sector's capability to ensure the orderly functioning of the economy and delivery of essential services;
> (e) Have a negative effect on the economy through the cascading disruption of other critical infrastructure and key resources; or
> (f) Undermine the public's morale and confidence in our national economic and political institutions.[3]

Based on HSPD-7, the following impacts are relevant when discussing the chemical sector:

- Impact on life and health (item a)
- Impact on government function (items b and c)
- Impact on the economy and/or the private sector (items d and e).

Societal response (item f) helps shape an incident and can either mitigate or exacerbate its effects. It is taken into account here as a source of possible amplification[4] of the three areas of impact listed above.

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[1]See the following website for more information: *http://www.whitehouse.gov/news/releases/2003/12/20031217-5.html.*

[2]For the purposes of this report, casualties include deaths and injuries.

[3]See the following web site for more information: *http://www.whitehouse.gov/news/releases/2003/12/20031217-5.html.*

[4]Richard Eiser, professor of psychology at the University of Sheffield, defines social amplification as "the many ways in which information about risks is amplified by some social processes and reduced by others. In processes of social amplification, a person's own knowledge is supplemented by other opinions which have been gathered and modulated by more or less official media. Individuals use such information to determine their own opinions. In

The statement of task for this study calls for a focus on potential *catastrophic* events. As mentioned previously, the U.S. Department of Homeland Security (DHS) *National Response Plan* defines a catastrophic incident as one that "results in large numbers of casualties and/or displaced persons, possibly in the tens of thousands." Similarly, an economic impact on the order of tens to hundreds of billions of dollars would be considered catastrophic. A catastrophic event is one whose consequences are so extensive that they overwhelm the ability of emergency responders, local, state, and federal government officials, and/or the general public to adequately and/or fully respond in a timely fashion.[5]

Incident Scenarios

Using its knowledge of and information about the chemical sector, and applying the methodology described in Chapter 3, particularly the supply chain characteristics presented in Figure 3.1, the study committee set out to envision attack scenarios involving the chemical infrastructure that would be significant enough to require a federal response. It found that all plausible scenarios generated in this red teaming type exercise that had the potential to reach a catastrophic level of impact fell into one of three basic categories:

1. High-volume release (either fixed site or transport),
2. Shortage, or
3. Misuse.

Each of these three scenarios is illustrated below with an example that

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addition, such signals can have more public consequences, for example when a public protest arises about some proposed new development. These developments also ripple outwards to other people, to new areas and to new groups. The opposite effect is social attenuation, when media and other key influencers decide not to stress a specific subject and interest in it becomes reduced.

"Social amplification can lead to decisions that are politically unavoidable and are perhaps socially understandable, but which produce less than optimum results if the problem is regarded as being one of resource allocation." Full paper available at *http://www.foresight.gov.uk/Intelligent_Infrastructure_Systems/long_paper.pdf*.

[5]Quarantelli, E. 2005. Catastrophes Are Different from Disasters: Some Implications for Crisis Planning and Managing Drawn from Katrina. Available at *http://understandingkatrina.ssrc.org/Quarantelli/*.

discusses the vulnerabilities, gives estimates of their consequences if exploited, and discusses recommendations that result.[6] The intention is not to review specific attack tactics and weapons for carrying out the scenario.

Estimates of the casualties resulting from a deliberate attack on the chemical infrastructure vary widely and have been controversial. A recent Congressional Research Service report details many of those estimates and discusses the differences in the analyses and assumptions that lead to them.[7] To preclude the possibility that the conclusions of this study could be dismissed because they are perceived as being based on flawed modeling of casualties, this report uses consequences from the historical accident record to provide existence proof for the consequences postulated in its scenario exercise.

Accident records are used, rather than a record of terrorist attacks, because there have been an extremely low number of terrorist attacks against the chemical infrastructure to date, and even fewer of these have had significant consequences. The Critical Infrastructure Terrorist Incident Catalog, a database of attacks against critical infrastructure with information on incidents going back as far as 1933, lists only 10 possible attacks against the chemical infrastructure, two of which are probable accidents; only one of the incidents definitively determined to be an attack is identified as having had significant consequences (i.e., property damage).[8]

Note that the casualty figures postulated here on the basis of the accident record cannot be taken as either minimum or maximum estimates. Casualties could be much lower if the correct convergence of factors does not occur. (Indeed, there are numerous historical examples available of similar accidents with much lower casualty figures.) It is also possible that casualties from a deliberate attack could be higher—one assumes that, unlike an accident, a deliberate attack will include efforts to control as many variables as possible in order to maximize casualties. However, in a deliberate attack, actual casualties will still depend on factors that are not entirely

[6]The scenarios included here are based on legal civilian chemical activities and do not include government-controlled military chemical agents or blatantly illegal activities such as illicit drug manufacturing.

[7]Schierow, L. 2005. *Chemical Facility Security*. RL31530. Washington, DC: Congressional Research Service.

[8]Monterey Institute of International Studies Center for Nonproliferation Studies. 2004. *Assessing Terrorist Motivations for Attacking Critical "Chemical" Infrastructure*. Monterey, CA. p. x.

under the attacker's control, such as meteorological conditions, the ability of the populace to shelter in-place, and the status of emergency preparedness and response. With these caveats, major accidents, although few in number relative to the size and long history of the chemical sector, can be used to provide a realistic estimate of the impact of an intentional attack. Lessons learned from these accidents can be used to better mitigate, prepare, and respond to future terrorist incidents, whatever the cause.

High-Volume Storage: An Incident Involving High Volumes of Toxic and/or Flammable Chemicals

The chemical industry stores many chemicals at its facilities in the form of raw materials, intermediates, products, and by-products. These products and by-products are then sold to customers who store them on their sites for direct use or for the manufacture of other products. The products of interest to a terrorist are chemicals that are toxic, flammable, or explosive, or a combination thereof. As Figure 4.1 indicates, this scenario has particular relevance to storage of inorganic chemicals, industrial gases, and petrochemicals and fossil fuels. Examples of inorganic chemicals that are toxic and stored in large volumes include chlorine, ammonia, and hydrogen fluoride. Industrial gases that are toxic include carbon monoxide; nitrogen and argon are asphyxiants; oxygen and hydrogen are flammable. Most petrochemical and fossil fuel products, intermediates, and by-products are flammable, while a few such as hydrogen cyanide, hydrogen sulfide, and phosgene are toxic.

Scenario

Location. The fictional River City is located on a major transportation corridor, serves as an inland port, and is a centralized hub of industrial production. The city abuts a major fresh waterway that serves as a source of drinking water for millions of people in the city and downstream from it. River City's terrain is moderately hilly and a majority of the population resides in low-lying areas, increasing the potential for a persistent toxic cloud to develop over a large residential area at a concentration hazardous to life and health. Limited evacuation routes are available to the community. River City has a population density greater than 8,000 people per square mile.

Time of Incident. The incident occurs during summer at or around mid-

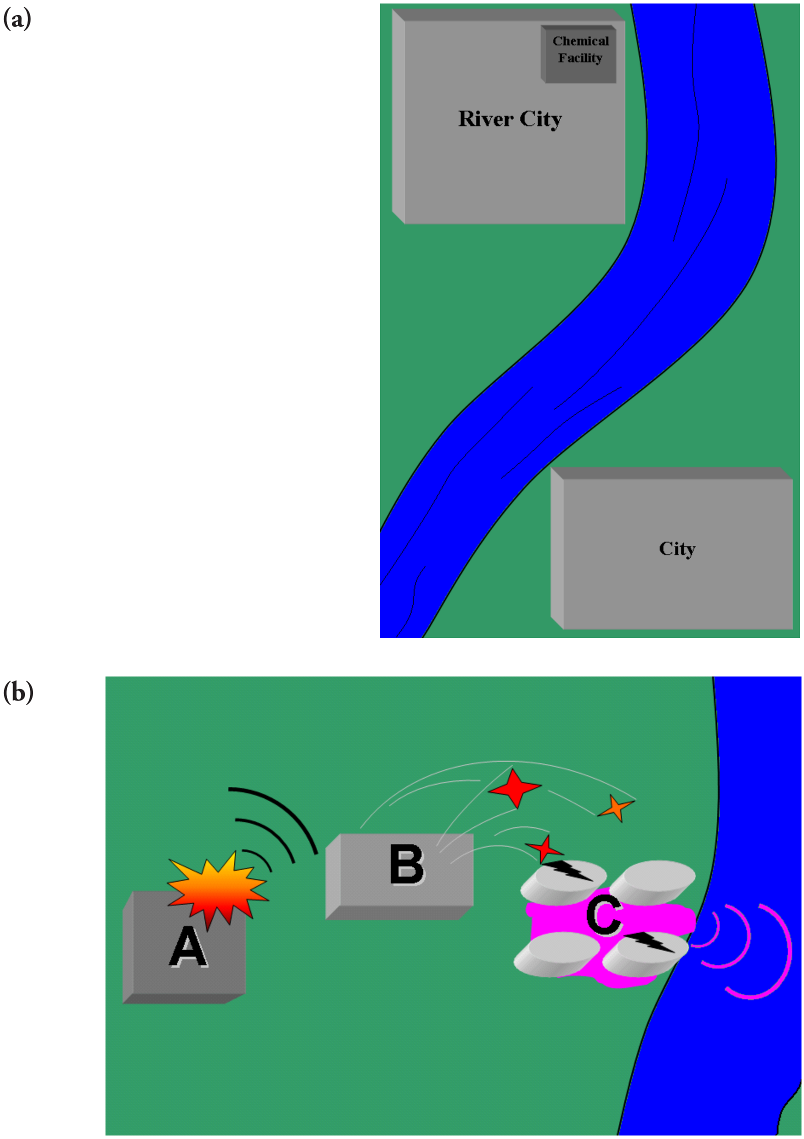

FIGURE 4.1 High-volume scenario: storage. As depicted in (a), a chemical facility is located within the midsized, fictitious River City. In the terrorist attack outlined in (b), Facility A is targeted first. The shock wave from this attack causes the destruction of Facility B. Shrapnel from Facility B hits Storage Tanks C, which then release toxic chemicals into the river, the source of drinking water for River City and downstream communities. See text for details.

night on a Saturday, Sunday, or holiday, when lower numbers and junior levels of permanent employees staff industrial facilities.

Ambient Conditions. The night is clear with a temperature of approximately 80° F. Wind speed is low (<4 miles per hour), and the wind is blowing from the chemical sources toward areas of high population density. The atmosphere is relatively stable.

Other Special Circumstances. Facility A is undergoing major maintenance and construction, so a large number of temporary contract staff is on-site, working around the clock.

Initiating Event (Stage One). Terrorists attack Facility A, triggering one or more explosions involving large storage containers of inorganic chemicals, petrochemicals, or fuels and specialty chemicals. (Examples might be potentially explosive fertilizers, light hydrocarbons capable of generating a large vapor cloud explosion, or high-energy reactive chemicals.) Multiple initiating pathways could be proposed that would generate significant pressure waves and projectile materials from the exploded storage vessels. The pressure waves and projectiles could further impact not only Facility A, but also facilities beyond its boundaries. Perpetrators provide plausible evidence to the media to demonstrate that the incident is due to terrorism.

Immediate Consequences (Stage One). The initial explosion results in 250 fatalities on-site, most of whom are contract employees; 100 people are killed off-site. 1,000 people are injured on-site; and 2,000 are injured off-site. The number of fatalities and injuries on-site severely compromises the ability of the facility to implement any emergency response activities. Most windows in the nearby vicinity are broken, destroying the capability for many to shelter in-place.

Cascading Events (Stage Two). In the proposed scenario, the potential exists for additional consequences resulting from the initial attack. These consequences can be described as "cascading event" consequences—for example, the initial explosion caused by the attack damages other equipment and causes further explosions or toxic releases that may be significantly more severe than the initial event. These events may not be anticipated or planned by the attacker, and in fact, the attacker may not even be aware of the potential for cascading events. The consequences described here would also obtain if disruption of the second facility was the result of a direct attack.

Pressure waves and projectiles from the explosion at Facility A strike large storage containers or rail cars at a separate plant (Facility B). The result is a loss of containment from the storage containers at Facility B, releasing highly toxic industrial chemicals (e.g., hydrofluoric acid, chlorine, ammonia, phosgene, hydrogen sulfide, sulfur dioxide, sulfur trioxide, hydrogen cyanide, selenium hydride). These chemicals will readily evaporate to form highly concentrated vapor clouds at the temperature postulated for the incident. The resultant vapor clouds will not dissipate or mix rapidly with the surrounding atmosphere because of the low wind speed and stable atmosphere that prevails at the time of the incident. The toxic gas cloud remains relatively concentrated and close to the ground, giving maximum potential exposure to the surrounding population. Toxic chemical exposures of residents in the community are increased because of broken windows and other structural damage to nearby property caused by the initial explosion, because of the timing of the event (people are at home), and because of limited evacuation routes.

Another potential cascading event is a release of toxic liquid from a storage tank into the river. Materials with a boiling point near normal atmospheric temperature—for example, monomethylamine (boiling point –6° C)—could form a toxic vapor cloud, yet remain partially liquid and flow into the river. The pressure wave and projectiles from the initiating explosion could impact storage vessels at a third facility, Facility C, releasing high volumes of liquid chemicals (e.g., petroleum fuels; chemicals that are persistent and bioaccumulative[9]) that flow into the river, the source of public drinking water and industrial water for River City and many downstream communities.

Immediate Consequences (Stage Two). On-site, 15 people are killed at Facility B; 1,000 are killed off-site; 20,000 people are exposed off-site, incurring injuries with a wide range of severity; business interruption occurs throughout River City. The consequence of Facility C's release grows subsequently in River City and the downstream communities as liquid chemical contamination of water supplies occurs.

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[9]Bioaccumulative: substances that concentrate in living organisms as they breathe contaminated air, drink or live in contaminated water, or eat contaminated food rather than being eliminated through natural processes.

Assessment of Impact

This assessment was made based on the historical analogies presented in Appendix A.

Impact on Life and Health. Release of a cloud of a hazardous toxic chemical would be expected to have a large, possibly catastrophic number of casualties. This fictional incident resulted in more than 1,000 deaths and 22,000 injuries. If a cascading spill of hazardous chemicals affects the water supply, a major impact would also be expected on downstream populations.

Impact on the Economy and the Private Sector. If Facility A is a petroleum refinery, immediate price hikes of refined products could occur due to anticipated shortages, even though no immediate inventory and distribution problems would be plausible because of large numbers of similar regional facilities and maintenance of transportation routes.[10] U.S. petroleum refining capacity has remained relatively constant for the last two decades despite expanded demand.[11] It is not anticipated that there would be larger regional or national impacts on distribution and transportation of chemicals. However, river transportation might be impacted for a short period of time as damage, contamination, and the possibility of a second attack are assessed.

Although the economic impact for the company affected in this scenario and its suppliers and customers could be enormous, the scenario as defined would not be considered catastrophic to the regional and national economy because of redundancies in operations at other facilities. Given that the event resulted from terrorism, social amplification could occur with further impact on the national economy.

Impact on Government Function. While this scenario would clearly be a major event and as an act of terrorism would invoke a federal investigation, because it is relatively localized it normally would not overwhelm the fed-

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[10]The March 23, 2005 explosion at the BP Amoco Texas City, Texas refinery, which was reported to represent about 3 percent of U.S. refining capacity provides a basis for this estimate of impact. Washington Post. 2005. Blast cuts refining capacity, March 25, p. E01.

[11]See the following web site for more information: U.S. Department of Energy, Energy Information Agency. Available at *http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/Refining_text.htm#U.S.%20Refining%20Capacity.*

eral government's capacity to respond. Local governments, and perhaps the state government, might be overwhelmed in their initial ability to respond to the demands of the disaster. The number of casualties would overwhelm all but the largest metropolitan medical systems and thereby necessitate significant regional and national coordination of emergency medical transport and care.

Possible government regulatory response, such as mandating specific security measures to protect facilities, may occur as a result, with a subsequent impact on the economic function of these companies and, in the aggregate, on the economy as a whole.

Societal Response. The societal response to any act of terror will presumably be greater than if the same consequences occurred through a nonterrorist event. In addition to the immediate reactions of the affected population, populations living near similar facilities would probably express concern that their locations are also targets. Terrorists might exacerbate such fears by announcing or attacking additional targets. Possible effects resulting from social amplification could include demands that chemical facilities nationwide be temporarily shut down, comparable to the cessation of air traffic after 9/11. If such a shutdown were to occur, the economic impact would be large. If large numbers of deaths occur as a result of water contamination (which has not occurred in previous cases of contamination), there may be a generalized fear of poisoning of the water supply. Demands on the government to deploy forces to protect chemical facilities may draw troops away from other priorities.

Discussion

The initial event, under an adverse convergence of circumstances, could have catastrophic levels of casualties but not catastrophic economic consequences. The potential for such a cascading event occurring is low, but not zero. The potential for a cascading event is also very site dependent. However, terrorists could achieve similar or greater impact by attacking multiple, either closely located or geographically dispersed, sites.

Although a coordinated event (multiple attacks at multiple sites occurring simultaneously or in a series) and a cascading event may have the same physical outcome, they could have different impacts. A cascading event involves successive events that are physically close to the initial event, but coordinated attacks can occur in geographically dispersed locations, possibly increasing public concern and straining the response capacity. Note that both coordinated attacks and cascading events could take place over some period of time—hours or even days. It may be difficult to recognize that coordinated attacks are occurring since terrorists benefit by disguising the relationships among events until their objectives are realized. However, early recognition of coordinated attacks is key to preventing further consequences and managing the potential for social amplification.

Release of toxic materials has greater potential to lead to a catastrophic number of casualties than release of flammable or explosive materials, since the impact distance of a toxic release can be much greater under adverse conditions. A toxic cloud low to the ground could cause large casualties among the general population, particularly if the public is not alerted in an effective or timely manner or trained to respond appropriately to the emergency.

The properties of the chemicals involved (flammable, toxic, etc.), rather than the category of chemicals (pharmaceuticals, petrochemical, etc.), determine the outcomes of this scenario. The impact of this scenario depends on the volume of chemical released, the release rate of the chemical, the properties of the chemical, the number of people living or working near the affected site, and the geographic and meteorological conditions. Fires and explosions are less conceivable to cause an event to reach a "catastrophic" level of casualties without a cascading event to increase their impact. Toxic events can result in catastrophic levels of casualties without cascading events.

It should be noted that toxic, flammable, and explosive chemicals of concern include intermediate products in addition to starting materials and end products. For example, the methyl isocyanate released in Bhopal, India, in 1984 was an intermediate product, manufactured at the site, stored in large quantities, and consumed to produce a final product.

Because this scenario involves fixed facilities, pre-planning with the emergency response community and public is more readily achieved. However, experience with prior accidents has shown that planning and response capability has been weak and poorly exercised in many communities.[12] Mutual aid agreements between communities might prove inadequate if multiple facilities are impacted simultaneously. Incident command structures would be similarly challenged. Also, the large number of casualties

[12]Merritt, C. 2005. Chemical attack on America: How vulnerable are we? Testimony before U.S. Senate Committee on Homeland Security and Governmental Affairs.

may reduce the effectiveness of emergency response, especially if emergency responders are directly impacted by the cascade of events.

Surveillance is feasible, but expensive. Terrorists are challenged by the increased security enhancements in the aftermath of 9/11, but there have been multiple media reports about the ineffectiveness and incomplete implementation of this security as well as significant security breaches.[13] Frequent nonterrorist incidents, as observed on the Chemical Safety Board's Incident News Reports[14] provide indications of potential vulnerabilities and attractiveness of chemical sector targets.

This scenario is set in an urban area. Storage of hazardous materials is necessary near urban centers—where gasoline is consumed, chlorine is used for water treatment, and factories are located near workers and consumers. Large storage tanks are present in urban centers; particularly those centers characterized as inland ports and centralized hubs of industrial production. Urban population centers have also grown to surround older factories. Increasing urban real estate valuation poses the additional vulnerability of nearby residential populations on former brownfield sites abutting active industrial facilities. [15]

Communication and analysis of information become complicated when incidents involve several facilities. Accessing the accuracy of information becomes more difficult, as is distributing that information to all involved in emergency response. The high human consequences of the initiating and cascading events will greatly constrain the flow of relevant information. Many companies already recognize the difficulties in communicating across facilities with different corporate control.

Even with complete disclosure of accurate information, the audience—first responders and the general public—may have difficulty absorbing all of the relevant information regarding each event. The media will also play a key role here, and its reporting can diminish or amplify the perceived consequences and risk associated with the release. Paradoxically, the media has become much more diverse and fractionated in marketing

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[13]U.S. plants open to terrorists, 60 Minutes broadcast on CBS, June 13, 2004.

[14]See the following web site for more information: *http://www.csb.gov/index.cfm?folder=circ&page=index.*

[15]Brownfields are real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

to the public even as corporate ownership has become concentrated, thereby posing additional challenges to a coherent understanding of the event and appropriate response.[16] The situation becomes more constrained as restrictive protocols (different levels of security clearances for emergency responders—police chiefs, fire chiefs, rank and file, volunteers) for information access are exercised in such complex scenarios.

Mitigating the Consequences of the High-Volume Toxic or Flammable Scenario

There are three possible approaches to mitigating the consequences identified in this scenario:

1. Reduce vulnerability by increased security.
2. Reduce consequence through detection and response.
3. Reduce vulnerability and consequence through inherently safer technologies.

Possible Science and Technology Investment

- Better fundamental understanding of material toxicity by inhalation. This will enhance our capacity to predict and model casualties. This includes the development of more Acute Exposure Guideline Levels (AEGLs),[17] toxicity dose-response relationships for all important chemicals, and predictive toxicology.
- Improved scientific models that utilize the chemical properties discussed above and more accurately predict the consequences for a toxic or flammable release. Currently the government sanctions the use of the ALOHA (Area Locations of Hazardous Atmospheres)[18] model for emergency responders, although some emergency responders use the manual

[16]See the following web sites for more information: (a) *http://www.congress.org/congressorg/dbq/media/;* (b) *http://www.corporations.org/media/#tv* .

[17]AEGLs are intended to describe the risk to humans resulting from once-in-a-lifetime, or rare, exposure to airborne chemicals. See the following web site for more information: *http://www.epa.gov/oppt/aegl/*.

[18]ALOHA is an atmospheric dispersion model used for evaluating releases of hazardous chemical vapors. See the following web site for more information: *http://www.epa.gov/ceppo/cameo/what.htm##haz.*

method in the EPA's *Technical Guidance for Hazards Analysis* or the Table of Protective Action Distances in the DOT *Emergency Response Guidebook,* while much of industry uses proprietary modeling software such as the PHAST (Process Hazard Analysis Software Tool)[19] model. The ALOHA model is very basic in its approach, and the results vary greatly from those obtained with the more sophisticated PHAST proprietary models. A more accurate model that can be used by everyone would greatly improve emergency response planning efforts and actual response.

- Enhanced real-time monitoring. This could contribute to early detection of and response to a chemical event. Investments could be made in the development of low-cost, accurate, and reliable sensors for toxic and flammable chemicals that could be placed strategically throughout a facility would provide early detection of chemical releases and aid emergency responders in monitoring the effects of the release.
- Improved equipment design, especially for chemical storage. For example, current methods used for storing materials in adsorbents at the cylinder scale—as is done at computer chip manufacturing facilities—might be scalable for use in large containers (i.e., rail cars or storage tanks). Other examples would include improved metallurgy to make storage tanks more resistant to terrorist weapons and fire suppression systems or water curtains for critical flammable and toxic storage tanks.
- Research to develop inherently safer alternatives and apply them to current processes that require high volumes of toxic or flammable materials. Previous reports have noted that changes adopted in the chemical industry to reduce costs, reduce environmental impact, or improve safety have also enhanced security by reducing the availability of hazardous materials for use in an attack.[20] These changes include the introduction of just-in-time manufacturing and delivery of starting materials or key intermediates, development of inherently safer processes that involve less toxic materials or smaller volumes of material, design of resilient engineered systems and process control systems, and introduction of "over-the-fence" or

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[19]PHAST examines the progress of a potential incident from the initial release to far-field dispersion including modeling of pool spreading and evaporation, and flammable and toxic effects. See the following web site for more information: *http://www.dnv.com/software/all/phast/productInfo.asp*.

[20]National Research Council. 2002. *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism.* Washington, DC: The National Academies Press, pp.113-114, 132.

on-site manufacturing to reduce transportation and storage. It must be noted, however, that some strategies to improve safety simply shift the risk—for example, nitrogen trifluoride (NF_3) is currently the most environmentally friendly way to deliver the fluorine molecule, which is needed for efficient chamber cleaning of chemical vapor deposition equipment in the electronics industry. A new on-site fluorine generator has been developed that eliminates the need to transport and store NF_3. However, the on-site generator relies on the dissociation of hydrofluoric acid (HF) to produce fluorine and therefore requires transportation, on-site storage, and handling of the more hazardous HF.[21] Other strategies to improve safety can in fact present new security challenges; proliferation risks from microreactors, which are inherently safer because they reduce the volume of chemical required to carry out a process, have been noted.[22] Pre-competitive research to develop new means or more cost-effective means to minimize the chemical inventory, develop new syntheses that utilize less hazardous material or less hazardous reaction conditions, and simplify existing chemical processes to eliminate unnecessary complexity will contribute to hazard mitigation in the chemical infrastructure.

High-Volume Transport

This is similar to the previous scenario but differs in two important respects. First, the hazardous chemical shipment is in transit, rather than at a fixed site. Second, the quantity of hazardous chemicals in any one truck or rail shipment is usually far less than the amount of hazardous materials stored at a fixed facility—large truck shipments are typically on the order of 40,000 pounds, while rail shipments can be four times higher than this.[23]

Figure 3.2 illustrates the key questions and supply chain characteristics to be considered during the decision-making process (i.e., high volume of materials, proximity of routes to population centers, robustness of contain-

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[21]Allgood, Charles. 2003. Delivering fluorine to the semiconductor industry: Balancing performance, safety, health, and environmental issues. *Gases and Technology* September/October 2003, 20-24.

[22]Nguyen, T.H. 2005. Microchallenges of chemical weapons proliferation. *Science* 309:1021.

[23]There are exceptions to this general statement. For example, liquefied natural gas tankers have average capacities of 138,000 m^3, and newer designs can hold up to 235,000 m^3. See the following web site for more information: *http://www.marinelog.com/DOCS/PRINTMMV/MMVFeblng1.html.*

ers) that can potentially lead to a catastrophic event in a scenario involving high volumes of chemicals in transport. As indicated in Figure 3.1, the categories of chemicals that are of particular concern in this scenario include inorganic chemicals, industrial gases, and petrochemicals and fossil fuels.

Scenario

Hazardous chemicals are shipped by truck, rail, marine vessel, pipeline, and sometimes air (in much more limited quantities). These shipments often travel near or through urban areas. If a terrorist event were to cause a release to occur, its location will play a large role in any consequences as well as the potential for a cascading event. Although the amount of hazardous chemical involved may be significantly less than at a fixed facility, an explosion or release could lead to significant casualties if it occurs near a population center. According to the 2004 U.S. Fire Administration survey, fewer than 16 percent of fire departments in this country have hazmat units.[24]

Assessment of Impact

This assessment was made based on the historical analogies presented in Appendix A for events involving high-volume chemical transport.

Impact on Life and Health. Depending on the chemical involved, the number of casualties could be significant—for example, hundreds to thousands of people in cases where there are large explosions or toxic materials are released in highly populated areas. Because of the quantity of chemical involved, multiple attacks at multiple sites would be required to produce numbers of casualties that would be considered catastrophic by the standards indicated in U.S. Department of Homeland Security (DHS) National Response Plan. (The values given in certain widely publicized planning scenarios reflect all those who are in a vulnerable zone, not the actual number of fatalities expected for a given set of meteorological conditions and wind directions.)

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[24]See the following website for more information: *http://www.usfa.fema.gov/applications/census/summary.cfm#table1.*

Impact on the Economy and the Private Sector. Impacts will depend heavily on the location of the incident and the hazardous chemicals involved. Economic impacts from most incidents would be localized. Greater impacts could occur as a result of cascading events, such as a tanker explosion that destroys a major terminal or other elements of the transportation infrastructure (e.g., bridges). Even so, these impacts will probably remain localized. Multiple events would be required to raise the level of economic impact to catastrophic levels.

Impact on Government Function. The federal government regularly investigates transportation safety incidents involving toxic materials. Any terrorist act would almost certainly invoke a federal response. Government function would be more seriously impacted only if a targeted attack using chemicals on a major government facility was successful at a time that many key members of government were present.

Societal Response. Social amplification will depend on the specific circumstances of an event. An event in an urban area may lead to calls for permanent bans on shipping of hazardous materials through urban areas, with subsequent economic impacts.

Discussion

Transportation introduces significant variability of location into the scenario discussed for facilities. This variability may work to either the advantage or the disadvantage of terrorists. Because the shipment is in motion, security precautions that are in place at fixed facilities do not exist, and modes of surveillance are quite different and can be difficult to sustain. The aggregation of hazmat rail cars in major transfer locations may be less secure than at fixed industrial facilities, and they may be located in or near urban environments. At the same time, because the location of the target is variable, additional planning is required to carry out an attack at the right place and time. There are also differences for the different modes of transport—trucks can deviate from typical routes, but the movement of rail cars is much more constrained.

Emergency response preparedness may be inadequate because preparations for a response in the exact location of the event may not be in place. Depending on the location of the incident, emergency response personnel may or may not be adequately trained and equipped for the hazardous chemicals involved in the incident, and the local population may or may not be prepared to take protective action. However, more densely populated areas are more likely to have significant hazardous materials response capabilities. Depending on the nature of the attack, there may or may not be time to take protective actions, at least in the immediate vicinity of the release.

Information may be a key factor in this scenario. Regulations require that shipments of dangerous goods display the nature of the hazards, usually on the transport container, and in general this information is easy to understand. While this information is essential to effective response and aids in enhanced safety in general, some are concerned that the information may assist terrorists in identifying specific targets.

Mitigating the Consequences of the High-Volume Toxic or Flammable Transport Scenario

Response to a scenario involving high-volume chemicals in transit is similar in all but a few ways to the response for a high-volume storage scenario at a fixed site. Key differences are that volumes tend to be smaller and the location is variable. In particular, transportation may pass through localities that are not prepared for hazmat response, do not have appropriate emergency planning, and are not prepared for hazmat incidents. In addition, local jurisdictions' ability to coordinate their emergency preparedness and response action with hazmat carriers is inherently more limited than with fixed-site facility operators.[25]

Possible Science and Technology Investment

Science and technology investments in areas described in the high-volume storage scenario will also help mitigate the high-volume transport scenario. The transport scenario leads to this additional potential science and technology solution:

- Rapid systems analysis and improved communication for emergency response.

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[25]See the following web site for more information: *http://www.greenpeace.org/usa/assets/binaries/analysis-by-us-naval-research.*

Chemical Shortage

Single supplier, long replacement time, and lack of substitution are supply chain characteristics that lead to a shortage scenario. Figure 3.1 indicates that this is of particular concern in the chemical categories of pharmaceuticals, inorganic chemicals, specialty chemicals, and petrochemicals and fossil fuels. Obviously the chemical in question must serve a critical need for a shortage to be of concern.

[*Note*: While this report was in review, DHS released an avian flu scenario that mirrors many of the consequences discussed below.[26] The significant difference between that scenario and this is that in this case, terrorist action negates the government's preparation to deal with a pandemic. This is a key element of the shortage scenario— it is by exacerbating an existing critical but perhaps manageable situation that terrorist action can cause a chemical shortage that is catastrophic in its consequences.]

Scenario

Location. United States.
Hypothetical Event.

The United States is preparing for what it is anticipating will be a "normal" flu season. Approximately 60 million flu vaccine doses are ready to be distributed.[27] Unfortunately, the strain that actually emerges proves to be resistant to the vaccine[28,29] and is unusually virulent—mortality is predicted at 5/1,000, only slightly less than the Spanish flu of 1918 (the mortality rate for those exposed to the Spanish Flu is estimated to have been slightly less than 1 percent with a case fatality of 2.5 percent).[30] For-

[26]Homeland Security Council. 2004. *Planning Scenarios: Executive Summaries.* Washington, DC. July.

[27]It was estimated that Aventis Pasteur, which produces the influenza vaccine in northeastern Pennsylvania and is the primary producer for the United States, generated about 58 million doses for a total supply of about 60 million vaccines for the United States for the 2004 flu season.

[28]Le, Q.M., M. Kiso, K. Someya, Y.T. Sakai, T.H. Nguyen, K.H.L. Nguyen, N.D. Pham, H.H. Nguyen, S. Yamada, Y. Muramoto, and T. Horimoto. 2005. Avian flu: Isolation of drug-resistant H5N1 virus. *Nature* 437:1108-1108.

[29]McNeil, D.C. 2005. Flu strain isolated in Vietnamese girl is resistant to drug, scientists report. *New York Times,* October 15, p. 10.

[30]National Research Council. 2005. *The Threat of Pandemic Influenza: Are We Ready?* Washington, DC: The National Academies Press, p. 8.

tunately, one of the existing antivirals has shown to be effective in greatly moderating the flu's adverse health effects. Although only 1 million 7-day courses of treatment are available, the sole manufacturer implements its emergency plan and promises 20 million 42-day treatments within 30 days at the bargain price of $200 per treatment course, or $4 billion. The Secretary of the U.S. Department of Health and Human Services (DHHS) publicly acknowledges the problem and states that with careful allocation of the limited supply of drugs and with new medication to be distributed "shortly," only a limited impact, comparable to the Asian flu, is expected. Information focusing on the high-risk population and instructions and recommendations on who should get the existing supplies and where they will be available are provided.

Terrorists attack the only production facility for the antiviral and disrupt the production and supply of the drug in the United States. Another manufacturer states that it can start a new production line in 90 days, with the first antivirals to be delivered in 120 days, after the peak of the flu season. The government and the original manufacturer begin negotiations with the second manufacturer over licensing, liability and price.[31] The U.S. government attempts to purchase medication from other countries that have their own stockpiles. However, there is concern that a worldwide flu pandemic, similar to the one in 1918, may emerge and foreign governments decide that they want to maintain their current stock rather than sell to the United States.

Several countries with weaker patent protection and drug regulation choose to manufacture their own version of the antiviral, both for their own population and for export.[32] This "gray market" generates and distributes some effective, some ineffective, and even some dangerous medications, which exacerbate the impact of the pandemic—the death toll, illnesses, and numbers requiring hospitalization.[33,34] The media highlights the role of the counterfeit drug market and its potential deadly outcomes,

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[31]Pollack, A. 2005. Roche agrees to talks with generic rivals on flu drug, *New York Times*. October 21. Available at *http://www.nytimes.com.*

[32]AFX News Limited. 2005. Thailand to make its own generic version of Tamiflu to fight bird flu. Available at *http://www.Forbes.com.*

[33]Homeland Security Council. 2004. *Planning Scenarios: Executive Summaries*. Washington, DC.

[34]Harris, G. 2005. From Washington, a story about a killer flu*, New York Times*. October 16. Available at *http://www.nytimes.com.*

thus increasing the population's psychological stress. Reports of senior government officials hoarding the drug for their own protection surface in some newspapers, leading the general public to believe that the government is underplaying the severity of the situation. "As the credibility of public authorities crumbled, so did social order."[35] Major corporations shift production overseas and are rumored to allow critical employees to travel overseas to take advantage of foreign drug treatments. Apparently U.S. multinationals have been stockpiling antivirals in anticipation of a pandemic.[36] The government considers confiscation of private stock to optimize distribution. Critical workers are using their personal allocation to protect their families instead of themselves, wreaking havoc with the government's allocation plans. Customs and Border Protection reports large numbers of U.S. citizens are traveling to Canada and Mexico to gain access to available medication. Our neighbors voice concern to the State Department and consider severely restricting cross-border traffic.

Assessment of Impact

By the time the pandemic has run its course and antivirals become widely available the United States has suffered several hundred thousand causalities and economic losses in excess of $150 billion.[37]

This assessment was made based on historical analogies (the 1918 pandemic and recent influenza outbreaks) and available attempts to predict potential consequences of an avian flu pandemic. See Appendix A.

Impact on Government Function. State and local governments in heavily affected areas may be overwhelmed in their attempts to respond adequately. During the 1918-1919 Spanish flu epidemic, hospitals in Washington, D.C., were overwhelmed with patients and those infected were placed in houses, apartments, and rooming houses, either with or without medical care. The pandemic may well affect enough localities that the federal

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[35]National Research Council. 2005. *The Threat of Pandemic Influenza: Are We Ready?* Washington, DC: The National Academies Press, p. 12.

[36]Pollack, A. 2005. Hoarding prompts halt in flu drug shipping. *New York Times.* October 27. Available at *http://www.nytimes.com.*

[37]Meltzer, M.I., N.J. Cox, and K. Fukuda. 1999. The economic impact of pandemic influenza in the United States: Priorities for intervention. *Emerging Infectious Diseases* 5:659–671.

government's capacity to respond is overwhelmed. National security considerations may lead to difficult allocation decisions and trade-offs regarding protection of the armed services, both at home and abroad.

Societal Reaction. Social amplification or attenuation can result as a consequence of the availability or lack of effective mitigation and preparedness initiatives; effective or ineffective leadership; and the ability or inability to provide accurate, up-to-date, and continuous information. The media plays an instrumental role in either amplifying or clarifying and explaining the impacts of shortages, as illustrated by coverage of the 2004 shortage of flu vaccine. Sensationalistic, biased, and inaccurate information contributes to the social amplification of these events. For example, the media may project and disseminate information indicating that without effective medical treatment about 1 million to 2 million people will die, leading to a widespread sense of vulnerability and helplessness that might cause a significant increase in hospital visits from individuals concerned that the symptoms they are experiencing are indication of a life-threatening disease. Accurate, clear, and understandable information, promptly provided by both the press and government officials, can make the government's response more manageable and the public's response helpful in managing the situation: "It is worth noting that this terror, at least in paralyzing form, did not seem to materialize in the few places where authorities told the truth."[38]

Discussion

Our market economy works to prevent shortages through competition. As discussed in Chapter 2, the chemical sector has redundant supply chains, moderate stockpiles of raw ingredients, and collaborative agreements to provide redundant manufacturing in an emergency or crisis situation, such as a shortage. The federal government also monitors the supply of some key pharmaceuticals and stockpiles them in order to ensure that there is no unexpected critical pharmaceutical shortage.

This scenario relies on particular characteristics of the market that could permit terrorists to capitalize on an existing situation and create a catastrophic event. The characteristic that makes the shortage scenario vi-

[38]Barry, J.M. 2005. 1918 Revisited: Lessons and suggestions for further inquiry. In *The Threat of Pandemic Influenza: Are We Ready?* Washington, DC: The National Academies Press, p. 58.

able is the uniqueness of the chemical compounds involved. In this scenario there is a targeted demand for a drug, and the drug itself has limited market applications—that is, it has no use other than to treat a limited number of flu strains. Under normal conditions there would be a very limited demand for the drug, resulting in only a single supplier and moderate stockpiles. If the sole supplier's capacity to manufacture the drug were eliminated, it is unlikely that an alternative means of production could readily be found. This is particularly true for compounds with a long manufacturing lead-time from raw material to finished product—in other words, drugs with a complex manufacturing process.

It is important to note that the federal government already has some safeguards in place to address pharmaceutical shortages. The Center for Drug Evaluation and Research (CDER) of the U.S. Food and Drug Administration[39] maintains a list of drugs critical to national well-being. CDER also assists the Centers for Disease Control and Prevention (CDC) to maintain the CDC's Strategic National Stockpile (SNS),[40] which has large quantities of medicine and medical supplies to protect the American public if there is a public health emergency severe enough to drain local supplies. Once federal and local authorities agree that the stockpile is needed, medicines can be delivered to any state in the United States within 12 hours. Each state has plans to receive and distribute SNS medicine and medical supplies to local communities as quickly as possible. However, if an event were to reach a "catastrophic" level, the SNS may not have an adequate amount of medications in stock to provide the appropriate doses to all who are impacted. The Department of Defense (DOD) also maintains a list of critical material and their suppliers deemed important to national security.[41]

Social amplification plays a key role in this scenario. The impact—economic impact, strain on limited medical resources, and possible social disruption— depends, in part, on how the event is portrayed by the media and how well the government responds and communicates with the public.

[39]See the following web site for more information: *http://www.fda.gov/cder/.*

[40]See the following web site for more information: *http://www.bt.cdc.gov/stockpile/.*

[41]The study committee was not able to review this list or meet with the DOD.

Possible Science and Technology Investment

Several steps can be taken to reduce the nation's vulnerability to chemical shortages. Some are outside the realm of science and technology: for example, extra security measures at suddenly critical manufacturing facilities or plans to permit confiscation of private stocks of a critical chemical in times of dire national need. Possible science and technology investments for this scenario include the following:

- Real-time national inventory tracking of certain chemicals, and the ability to predict how extra normal but nonterrorist events might create the opportunity for terrorist-induced catastrophic shortages. This would greatly aid planning and protective measures.
- Flexible or swing manufacturing contingency plans (perhaps including trial manufacturing runs for the most critical chemicals).
- Collection of data and the development of models to enable rapid, high-confidence determination of how a limited supply of a chemical should be distributed to minimize consequences. Building and executing an effective simulation with all the appropriate feed data might not be feasible on an emergency time line.
- Social science to improve response and communication. This includes implementing current knowledge about disaster response from the social science community, as well as additional studies to determine the types of information, best communication channels, and most effective delivery of information required to reach all populations affected by such an event.[42] Ensuring that credible, well-informed technical spokespeople, either government employees or private individuals, are available to communicate information about the event and actions being taken to mitigate the shortage should enhance a positive public response to the event.

The analysis used here did not identify any obvious key chemicals for which a shortage with catastrophic national consequences could readily be induced. Further economic analysis of the chemical industry would be appropriate to either verify this conclusion or identify chemicals that could, with exacerbating natural events, result in catastrophic shortages.

[42]Lindell, M.K. and R.W. Perry. 2004. *Communicating Environmental Risk in Multiethnic Communities.* Thousand Oaks, CA: Sage.

Misuse of Materials

Lack of control is the characteristic that makes the misuse scenario possible. As Figure 3.1 indicates, inorganic chemicals, industrial gases, specialty chemicals, consumer products, and petrochemicals or fossil fuels should be of particular concern in this scenario.[43] Because of the ubiquitous nature of consumer products in the U.S. economy, they have significant potential for widespread social amplification.

Scenario

Small quantities of chemicals can produce only small, direct impacts over small or large impact areas, but specific locations or situations might be targeted specifically to cause social concern and amplify the physical impact, or repeated incidents could cause indirect impacts that exceed the direct impacts.

Location. Sunnytown, is a fictional midsized city located relatively close to major population centers, none of which have been subjected to terrorist incidents in the past. The local population, although concerned about terrorism, has no special concern that its city would be a potential target.

Initiating Event (Stage One). Terrorists contaminate a popular over-the-counter consumer product in the greater Sunnytown area with a highly toxic chemical. Depending on their objectives, these toxins can be either relatively common poisons that would cause death quickly, and would be relatively easy to identify, or more esoteric toxins that might be difficult to

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[43]One obvious misuse scenario is use of ammonium nitrate fertilizer or black and smokeless powders to create an explosive device. Since explosive risks have been and are being extensively considered elsewhere, this report does not deal with that scenario. See, for example, National Research Council. 2004. *Existing and Potential Standoff Explosives Detection Techniques*. Washington, DC: The National Academies Press. Also note previous reports discussing taggants. While this has been discussed primarily for use in explosive materials, especially black and smokeless powders that are typically used in pipe bombs, taggants might have potential usefulness in this loss-of-control scenario. See National Research Council. 1998. *Black and Smokeless Powders: Technologies for Finding Bombs and the Bomb Makers*. Washington, DC: National Academy Press. That report concluded that use of taggants was not warranted in the United States at that time, but that if the "threat increased substantially in the future," such a conclusion might be reconsidered.

identify or track, and/or whose mode of action is slower, allowing multiple acts to occur before local public health and safety authorities recognize the threat.

Immediate Consequences. Depending on the extent of the tampering, the mode of action of the toxin, and the time required for authorities to realize and take actions to mitigate the incident, casualties could range from fewer than ten up to many dozens or possibly hundreds.

Cascading Events (Stage Two). Social amplification would be expected no matter what the extent of the actual deaths involved. If the poisonings have the appearance of being widely dispersed (e.g., multiple toxins are used, a wide variety of products are targeted—including food, pharmaceuticals, health and beauty products), social amplification would be more extreme, possibly leading to difficulties as people locally, regionally, or nationwide stop buying products they suspect might be contaminated and use up their own personal inventories of these products.

Supply Chain Consequences. Producers of the affected consumer product may experience significant economic downturns as affected and unaffected populations stop buying their goods.

Assessment of Impact

This assessment was made based on historical analogies presented in Appendix A for events resulting from misuse of a small or targeted amount of material.

Impact on Life and Health. It is difficult to conceive of a tampering scenario using a chemical toxin that would lead to massive casualties. The number of individual products compromised would have to be enormous, enhancing the chances of detection, and the source of the poisoning would probably be identified quickly, especially if the same toxin and same product were involved in all cases.

Impact on the Economy and the Private Sector. Because these incidents are so site and method specific, it is difficult to make generalities regarding economic impact. A single tampering incident that leads to a single illness would not be expected to have a major impact. However, multiple incidents could have significant economic impact on the targeted company. If a series of cases affecting a key pharmaceutical leads the population to believe that the entire supply is tainted, this could have a significant national impact if a replacement is not readily available or public concerns about tampering cannot be allayed quickly.

Impact on Government Function. The government response to such an incident would be significant, possibly very large in comparison with the small number of lives lost. The anthrax attacks in the fall of 2001—although not completely analogous to this scenario—are instructive in illustrating that a massive federal response can occur in the event of a comparatively small loss of life.[44] If tampering is widespread and not immediately contained, a large federal effort would occur to stabilize the situation. However, such an incident would not overwhelm the ability to respond effectively at the federal level.

Societal Reaction. A scenario involving tampering will meet the definition of catastrophic only by invoking significant social amplification. This type of scenario, where the characteristics include poisoning of common items and multiple attacks that may be widely dispersed geographically, may lead to the perception that the attacker is anywhere and everywhere. Large portions of the population may shun buying or using the targeted consumer products in response to this tampering, whether or not they are actually at risk.

Discussion

While it is difficult to conceive of a tampering case that would lead to catastrophic numbers of casualties, the fact that this type of attack is relatively easy to accomplish, and involves small quantities of toxic materials, makes this scenario more amenable to multiple coordinated incidents and makes any attempt difficult to detect and intercept prior to its implementation.

[44]As a result of the anthrax attacks there were five deaths; the U.S. government spent $1.6 billion on emergency preparedness in local jurisdictions for biological attacks and more than $200 million for the cleanup of affected facilities. Kempter, J. 2005. Update on Building Contamination, presented to the National Academies' Board on Chemical Sciences and Technology, April 26.

Perhaps the greatest vulnerability posed by this scenario is the potential for large social amplification. It appears that the anthrax attacks in 2001 were timed to take advantage of the uncertainty and insecurity felt by the American public after the September 11th attacks a month earlier. A tampering attack may likewise attempt to maximize the public's reaction to a prior event in an effort to create as much disruption as possible.

Manufacturers of consumer products and pharmaceuticals expend a great deal of effort to prevent product tampering. Because the consequences can be devastating for the company targeted, industry has significant interest in quality control of its products. In addition to criminal investigation, the role of the federal government can be significant, particularly in scenarios where multiple unrelated products are targeted simultaneously. In general, quick, effective action to respond to a tampering case, combined with effective and open communication to the general population, provide the best opportunities to attenuate the social amplification that will almost certainly occur in response to such an incident.

It may be all but impossible to prevent a determined attacker from successfully tampering with a product. However, the response by Johnson & Johnson to the Tylenol poisonings in 1982 illustrates the benefits of outreach to the public. Although the company lost approximately $1 billion in market value as an immediate result of these incidents, its quick actions in response to the poisonings (including recall and destruction of existing inventory and development of tamper-proof packaging), performed in an open and transparent manner, allowed the company to recover 70 percent of its market share for Tylenol.[45] When a similar incident occurred in 1986, Johnson & Johnson again acted quickly and recalled inventory from all outlets, not just those in affected areas. These actions helped to lessen the overall impact of these events on the company and preserved Tylenol as a viable brand.

In cases of widespread tampering involving multiple products, the affected companies will play a significant role in addressing public concerns, but coordinating bodies from the private sector (e.g., trade associations) and public sector agencies must play a role in relaying clear, accurate, and concise information to the public. The government's response to the an-

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[45]See the following web site for more information: *http://www.mallenbaker.net/csr/CSRfiles/crisis02.html.*

thrax attacks in 2001 is useful in illustrating both the positive and the negative aspects of crisis management and effective communication to the public in an ambiguous environment.

Mitigating the Consequences of the Misuse Scenario

The misuse scenario reaches a catastrophic level of impact only through social amplification. Therefore, consequences are best mitigated through effective communication and emergency response.

Possible Science and Technology Investment

- Increase the speed and accuracy of the population protection process: detect, classify, notify, warn, and respond.
- Improve response and communication. This includes social science research to determine the types of information, best communication channels, and most effective delivery of information required to reach all populations affected by such an event.

5

Managing Risk

As seen from the discussion in the previous chapters, and as demonstrated in the scenarios presented in Chapter 4, social factors can be as important as technical factors in determining the preparedness for and consequences of a deliberate disruption of the chemical infrastructure. This chapter presents a model of disaster impacts and discusses risk perception, interdependent security, and consequent decision making from the individual chemical plant to broader societal impacts. These concepts are useful to develop strategies for managing the vulnerabilities presented by the chemical infrastructure in a cost-effective manner. They point to management of emergency planning and response, and communication and social response, as important factors in reducing the likelihood that the consequences of an event will reach catastrophic proportions.

SOCIETAL IMPACTS OF HAZARDOUS INCIDENTS

Research conducted over the past 50 years has yielded a broad understanding of the process by which hazardous incidents affect local communities and the larger social units of which they are a part.[1] Hazardous inci-

[1](a) Cutter, S.L. 1996. Vulnerability to environmental hazards. *Progress in Human Geography* 20:529-539; (b) Lindell, M.K., and C.S. Prater. 2003. Assessing community impacts of natural disasters. *Natural Hazards Review* 4:176-185; (c) Mileti, D.S. 1999. *Disasters by Design*. Washington, DC: Joseph Henry Press; (d) Lindell, M.K., C.S. Prater, and R.W.

dents are events that are perceived by some segments of society as producing unacceptable impacts or as indicating the danger that such impacts might occur in the future. These incidents do not necessarily produce large numbers of casualties or damage, but they can result in a societal response disproportionate to the risks involved, relative to that posed by natural disasters, such as earthquakes and hurricanes.

A Model of Disaster Impacts

There are many apparent contradictions in the societal management of risk that can be explained (although far from perfectly) by recent models of disaster impacts[2] and the social amplification or attenuation of risk.[3] One model, the Disasters Impact Model (DIM) shown in Figure 5.1, describes the determinants of disaster consequences. The effects of hazardous incidents are determined in part by three pre-impact conditions: (a) hazard exposure, (b) physical vulnerability, and (c) social vulnerability. When a hazardous incident occurs, it is subject to event-specific (d) hazardous incident characteristics that combine with the pre-impact conditions to produce (e) physical impacts. In turn, these physical impacts cause (f) social impacts. However, the physical impacts can be reduced by (g) improvised emergency response, and the social impacts can be reduced by (h) improvised disaster recovery activities. In addition, the impacts of the incident can be further reduced by means of pre-impact hazard planning and management actions such as (i) hazard mitigation practices and (j) emergency preparedness practices that reduce the physical impacts and (k) recovery preparedness practices that reduce the social impacts.

Some shortcomings must be kept in mind when applying the DIM to the chemical sector:

Perry. In press. *Emergency Management Principles and Practices.* Hoboken, NJ: John Wiley and Sons.

[2]Lindell, M.K., and C.S. Prater. 2003. Assessing community impacts of natural disasters. *Natural Hazards Review* 4:176-185.

[3](a) Kasperson, J.X., R.E. Kasperson, N. Pidgeon, and P. Slovic. 2003. The social amplification of risk: Assessing fifteen years of research and theory. in N. Pidgeon, R.E Kasperson, and P. Slovic (eds.), *The Social Amplification of Risk.* New York: Cambridge University Press, pp.13-46; (b) Kasperson, R.E., O. Renn, P. Slovic, H.S. Brown, J. Emel, R. Goble, J.X. Kasperson, and S.J. Ratick. 1988. The social amplification of risk: A conceptual framework. *Risk Analysis* 8:178-187.

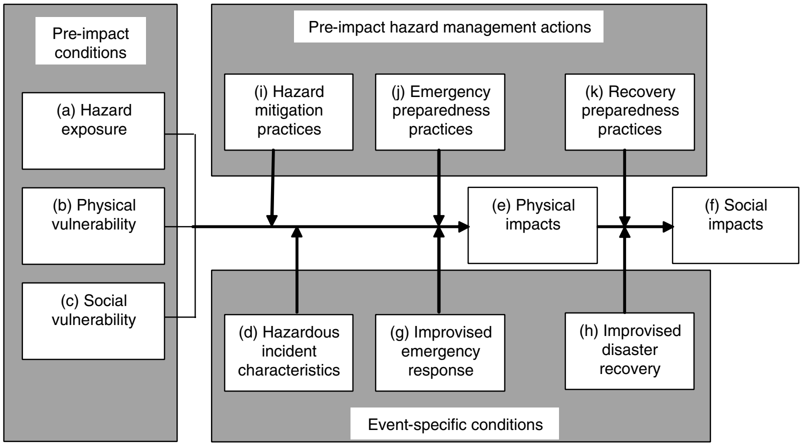

FIGURE 5.1 The Disasters Impact Model: a model of hazardous incident impacts. SOURCE: Federal Emergency Management Agency. Introduction to Emergency Management Textbook. Available at *http://training.fema.gov/EMIWeb/edu/introtoEM.asp*.

- The effects and relationships displayed in the DIM are not linear or unidirectional as shown. There are interdependencies and interactions among and between these components. There are many complexities within the model and interaction may occur within components not depicted in the figure.
- The DIM, which was developed from findings of research on natural hazards, can best be applied to chemical incidents that have a well-defined geographic impact area, such as the release of hazardous materials from a fixed site or in transport. To date there has been no research to confirm that the DIM can be applied to incidents lacking a well-defined geographic impact area, such as chemical contamination of food or pharmaceuticals.
- The DIM lacks analytic methods for assessing remote downstream supply chain impacts of the destruction of a single facility or small group of facilities.

Nonetheless, some useful general conclusions can be drawn from the DIM. The following sections describe the components of the DIM in greater detail.

Pre-impact Conditions

Pre-impact conditions play a large role in determining the consequences of a hazardous event.

Hazard exposure refers to the geographical areas that could be affected by the impact of a hazardous incident. For example, the areas around chemical facilities and their transportation routes can be mapped to identify the locations, known as *vulnerable zones*, where dangerous levels of chemical exposures could occur if some or all of the contents of a chemical container were released.[4] There are 9 categories of hazardous materials listed by the Department of Transportation,[5] which include explosives, gases, flammable liquids, flammable solids, oxidizers and organic peroxides, toxic (poisonous) materials and infectious substances, radioactive materials, corrosive materials, and miscellaneous dangerous goods. Only a few of these are sufficiently dangerous, stored or shipped in large enough quantities, or located close enough to populated areas to produce direct damage or large numbers of casualties. Many of these chemicals have been identified as extremely hazardous substances (EHSs) in accordance with the requirements of Section 312 of the Emergency Planning and Community Right to Know Act of 1986 or Section 112(r) of the Clean Air Act Amendments of 1992. In most communities, vulnerable zones have been estimated using the U.S. Environmental Protection Agency's (EPA's) Risk Management Plan (RMP) estimates required by the Clean Air Act Amendments. Vulnerable zones are areas around a facility in which people could, but would not necessarily, be exposed to harm by a worst-case event. The portion of the vulnerable zone impacted in an actual event is dependent upon factors such as meteorological conditions, wind speed, wind direction, et cetera, and is expected to be some fraction of the total vulnerable zone. Therefore the number of people exposed in an actual event would be lower than the total number of people living in the vulnerable zone.

Physical vulnerability refers to the susceptibility of persons and structures to the impacts of a hazardous incident. In the case of hazards to per-

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[4]U.S. Environmental Protection Agency, Federal Emergency Management Agency, and U.S. Department of Transportation. 1987. *Technical Guidance for Hazards Analysis*. Washington, DC.

[5]Department of Transportation, Transport Canada, and Secretariat of Transport and Communications. 2000. *Emergency Response Guidebook*. Washington, DC.

sons, this means deaths, injuries, or illnesses from extreme temperatures, blast pressures, and toxic chemicals.

In the case of structures, physical vulnerability usually means susceptibility to damage from fire and blast, but structures can also be vulnerable to toxic chemicals if the materials from which they are constructed are reactive with the chemicals involved or are difficult to decontaminate.

Social vulnerability can be characterized as people's inability to anticipate, avoid, respond to, or recover from hazard impacts.[6] Thus, social vulnerability addresses the degree to which people lack information about hazards; are located close to hazard sources; live or work in buildings having low hazard resistance; have little or no access to warnings, training on how to respond, evacuation transportation, and shelter locations; and have limited assets to support recovery from disaster impacts. Social vulnerability is determined in part by the state of a community's emergency preparedness.[7] In many cases, households' social vulnerability is systematically related to demographic characteristics such as gender, age, education, income, and ethnicity.

Event-Specific Conditions

In addition to existing pre-impact conditions, the consequences of an actual event will depend upon event-specific conditions—those unique conditions that obtain at the time of the event.

Hazardous Incident Characteristics. These include the availability of environmental cues, speed of hazard onset, scope of hazard impact, and duration of hazard impact.[8] When hazardous incidents occur infrequently, with rapid onset, no environmental cues, large scope of impact, and long duration, it is difficult for households and local governments to improvise a

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[6]Blaikie, P., T. Cannon, I. Davis, and B. Wisner. 2004. *At Risk: Natural Hazards, People's Vulnerability and Disasters,* 2nd edition. New York: Rutledge.

[7]To address some of the issues of a vulnerable population such as community preparedness, risk perception, and the community's overall response to terrorism, the Department of Homeland Security has sponsored the National Consortium for the Study of Terrorism and Responses to Terrorism (START) at the University of Maryland. See the following web site for more information: *http://www.start.umd.edu/.*

[8](a) Dynes, R.R. 1974. *Organized Behavior in Disaster.* Columbus, OH: Ohio State University Disaster Research Center; (b) Lindell, M.K. 1994. Perceived characteristics of environmental hazards. *International Journal of Mass Emergencies and Disasters* 12:303-326.

successful emergency response. Although these conditions apply most directly to the storage and transportation scenarios, they also seem quite relevant to the chemical shortage and chemical misuse scenarios, as well.

Improvised Emergency Response. When an incident occurs, the emergency response organization must perform four basic functions: emergency assessment, expedient hazard mitigation, population protection, and incident management.[9] Emergency assessment consists of those diagnoses of past and present conditions and prognoses of future conditions that guide the emergency response. Expedient hazard mitigation refers to actions that emergency personnel take to limit the magnitude of the disaster's impact (e.g., sandbagging a flooding river, patching a leaking railroad tank car). Population protection refers to actions—such as sheltering-in-place, evacuation, and mass immunization—that protect people from hazardous agents. Incident management consists of the activities by which the human and physical resources used to respond to the emergency are mobilized and directed to accomplish the goals of the emergency response organization.

As discussed further below, emergency response personnel increasingly use emergency preparedness practices such as planning, training, equipping, and exercising to guide their emergency response. However, emergency response personnel may have to improvise emergency response actions for one of two reasons. First, they might implement *maladaptive* actions because they have inadequate plans, training, facilities, equipment, or materials. Second, they might implement *adaptive* actions because they recognize that specific characteristics of an incident require actions that differ from those prescribed by emergency operations plans and procedures.

Improvised Disaster Recovery. During disaster recovery, the recovery organization must perform five basic functions: disaster assessment, debris clearance, resource management, physical reconstruction, and business resumption. Disaster assessment involves evaluating damage and casualties, and debris clearance involves removing damaged infrastructure, structures, contents, and vehicles. Resource management involves controlling the flow of personnel, equipment, and materials into the impact area, and physical reconstruction involves rebuilding or replacing damaged infrastructure, structures, contents, and vehicles. Finally, business resumption involves re-

[9](a) Lindell, M.K., and R.W. Perry. 1992. *Behavioral Foundations of Community Emergency Planning*. Washington, DC: Hemisphere; (b) Lindell, M.K., C.S. Prater, and R.W. Perry. in press. *Emergency Management Principles and Practices*. Hoboken, NJ: Wiley.

establishing links to employees, suppliers, distributors, and customers. In scenarios lacking a specific incident scene—the chemical shortage and misuse scenarios—there is no physical damage, so debris clearance and physical reconstruction will not take place. However, disaster assessment, resource management, and business resumption will still be needed. As is the case with improvised emergency response, improvised disaster recovery can be necessary because of inadequate recovery preparedness or because recovery personnel recognize distinctive characteristics of an incident that indicate a need to deviate from the pre-impact recovery plan.

Pre-impact Hazard Management Actions

Communities are best able to protect themselves from low-probability, high-consequence incidents by engaging in three pre-impact hazard management interventions—hazard mitigation, emergency preparedness, and recovery preparedness—to reduce the physical and social impacts of hazardous incidents. Hazard mitigation practices provide passive protection to persons and property at the time an incident occurs, whereas emergency preparedness practices develop the resources needed to support an active emergency response. Recovery preparedness practices provide the financial and material resources needed to reestablish normal patterns of social and economic functioning after an incident has been stabilized.

More specifically, **hazard mitigation practices** include hazard source control activities to prevent chemical releases, land use practices to limit the number and types of structures and persons that are exposed to a hazard, and building construction practices to prevent damage and casualties. For chemicals, hazard source control includes process design, facility construction materials, and operation and maintenance practices that reduce the probability of an incident. Hazard source control also includes flare towers, water curtains, or other devices that would reduce the magnitude of the impacts if an incident occurred.[10] Land use practices include siting hazardous chemical facilities away from densely populated areas or locations of special facilities such as schools, nursing homes, or hospitals.[11] Appropriate land use practices also include limiting residential and commercial con-

[10]Prugh, R.W., and R.W. Johnson. 1998. *Guidelines for Vapor Release Mitigation.* New York: American Institute of Chemical Engineers Center for Chemical Process Safety.

[11]Lindell, M.K. 2006. Hazardous materials. In American Planning Association, *Planning and Urban Design Standards.* New York: John Wiley & Sons. pp. 168-170.

struction and the siting of special facilities within the vulnerable zones of hazardous chemical facilities. Finally, building construction practices ensure that residential and commercial structures located close to hazardous chemical facilities can withstand the forces of fires and explosions and can resist the infiltration of contaminated air from releases of toxic or flammable gases.

Emergency preparedness practices develop the resources needed to support an active emergency response. These involve the development of emergency response plans, procedures, and training programs, the acquisition of facilities, equipment, and materials likely to be needed to support an emergency response; and the performance of drills and exercises to test the emergency response organization.[12] To support the emergency assessment function, facilities, carriers, and local jurisdictions must develop the capability to promptly and accurately detect a chemical threat and to project its potential impact area to identify areas that require population protection actions. Consumer product and pharmaceutical producers and public health departments must have a prompt detection capability and an ability to carry out a response such as product recall in the event of contamination. To support the expedient hazard mitigation function, there must be an ability to control leaks, spills, and fires, to stabilize containers;[13] and to quickly repair damaged production systems. To support the population protection function, it is necessary to have a capability for protective action decision making, population warning, protective action implementation (e.g., evacuation traffic management and evacuation transportation support, sheltering-in-place, use of alternative products, recall and collection of possible contaminated product), search and rescue, and transportation and treatment of the injured.[14] To support the incident management function, there must be a capability to activate emergency response organiza-

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[12]Lindell, M.K., and R.W. Perry. in press. Onsite and offsite emergency preparedness for chemical facilities and chemical transportation. In S. Lee. (ed.) *Encyclopedia of Chemical Processes.* New York: Marcel Dekker.

[13]Lesak, D.M. 1999. *Hazardous Materials: Strategies and Tactics.* Upper Saddle River NJ: Prentice-Hall.

[14](a) Lindell, M.K., and R.W. Perry. 1992. *Behavioral Foundations of Community Emergency Planning.* Washington, DC: Hemisphere Press; (b) Lindell, M.K., and R.W. Perry. in press. Planning and preparedness. In K.J. Tierney and W.F. Waugh, Jr. (eds.) *Emergency Management: Principles and Practice for Local Government, 2nd Edition..* Washington, DC: International City/County Management Association.

tions, coordinate and document their activities, acquire additional resources, and communicate with the public.

Recovery preparedness practices provide the financial and material resources necessary to reestablish normal patterns of social and economic functioning after an event has been stabilized. These involve establishing pre-impact recovery organizations comprising representatives of all organizations that would participate in an actual disaster recovery, as well as developing a recovery plan that establishes the structure of the disaster recovery organization. In addition, recovery preparedness also involves the development of procedures to guide damage assessment; debris clearance (contamination cleanup in the case of persistent chemicals); resource management; physical reconstruction of infrastructure and residential, commercial, and industrial buildings; and business resumption. Finally, recovery preparedness also includes procedures for integrating hazard mitigation into the recovery process. This latter step ensures that the affected community is less vulnerable to future incidents.[15]

Hazardous Incident Impacts

The principal **physical impacts** of a hazardous incident are casualties and damage, each of which can be caused by a primary hazard (e.g., an explosion or toxic release) or a secondary hazard (e.g., a toxic chemical release caused by an explosion as described in the high-volume scenario in Chapter 4). In addition to the direct casualties and damage caused by the primary and secondary hazards, there can be indirect physical impacts. For example, the destruction of a chemical plant that is the sole producer of a nonsubstitutable commodity could have the indirect effect of suspending production of all downstream products.

The **social impacts** of a hazardous incident can be classified as psychological, demographic, economic, and political.[16] Psychological impacts can be categorized as emotional, cognitive, and behavioral. Emotional impacts include such negative manifestations as depression and post traumatic stress

[15]Schwab, J., K.C. Topping, C.C. Eadie, R.E. Deyle, and R.A. Smith. 1998. *Planning for Post-disaster Recovery and Reconstruction.* PAS Report 483/484. Chicago IL: American Planning Association.

[16]Lindell, M.K., and C.S. Prater. 2003. Assessing community impacts of natural disasters. *Natural Hazards Review* 4:176-185.

disorder but can also include positive manifestations such as a sense of community identification from helping to save the lives and property of others.[17] Cognitive impacts are most likely to be changes in people's perceptions of hazard exposure, hazard impact characteristics, personal consequences of hazard exposure, and characteristics of alternative protective actions.[18] Behavioral impacts include changes in people's daily activities such as work, education, recreation, social interaction, and basic functions such as eating and sleeping.[19]

A principal focus of the DIM is on the ways in which physical impacts such as casualties and damage cause social impacts through the *direct* experience of the impact area population. However, some of those in the impact area do not experience damage or casualties, and this is also true for the entire population outside the impact area. Unlike direct experience, which occurs when people are themselves casualties or experience damage to their own property, vicarious experience occurs when people learn about casualties or damage experienced by others. Direct experience has a very powerful effect on people's beliefs and behavior, but it generally happens to a relatively small proportion of the population. By contrast, vicarious experience has a weaker effect on people's beliefs and behavior than direct experience, but can affect a much larger proportion of the population.

Demographic impacts are defined by changes in the population of the impact area including births, deaths, and migration (e.g., in- and out-migration).[20] **Economic impacts** are defined by the changes in employment for households or profitability for businesses.[21] In many cases, "losers" are counterbalanced by "winners" at the local level. For example, one

[17]Kaniasty, K., and F. Norris. 1999. The experience of disaster: Individuals and communities sharing trauma. Pp. 25-61 in R. Gist and B. Lubin (eds.) *Response to Disaster: Psychosocial, Community and Ecological Approaches*. Philadelphia, PA: Brunner/Mazel.

[18]Lindell, M.K., and R.W. Perry. 2004. *Communicating Environmental Risk in Multiethnic Communities*. Thousand Oaks, CA: Sage.

[19]Houts, P.S., P.D. Cleary, and T.W. Hu. 1988. *The Three Mile Island Crisis: Psychological, Social and Economic Impacts on the Surrounding Population*. University Park, PA: Pennsylvania State University Press.

[20]Smith, S.K., J. Tayman, and D.A. Swanson. 2001. *State and Local Population Projections: Methodology and Analysis,* New York: Kluwer.

[21]Zhang, Y., M.K. Lindell, and C.S. Prater. 2004. Modeling and managing the vulnerability of community businesses to environmental disasters. Paper presented at the *Association of Collegiate Schools of Planning.*

business's inability to supply its products to customers can mean additional revenues for its competitors; money that victims spend on rebuilding their damaged homes generates revenues for construction companies. Thus, some of what appear to be economic *losses* are in fact only economic *shifts*. **Political impacts** include the enactment of regulations and legislation.[22]

Opportunities to Improve Hazard Management

The above discussion of the Disaster Impacts Model suggests a number of areas in which research investments can significantly improve the nation's ability to manage the vulnerabilities to and consequences of terrorist attack or other catastrophic disruption of the chemical infrastructure. Investments in *hazard or vulnerability analysis* for the storage and transportation scenarios can provide the information on pre-impact conditions that is needed to identify locations with the greatest hazard exposure, structures with the greatest physical vulnerability and population segments with the greatest social vulnerability. Investments in *pre-impact hazard management actions* can provide better ways to reduce vulnerability before an incident occurs (hazard mitigation), respond effectively when an incident does occur (emergency response preparedness), and recover rapidly after an incident has been terminated (recovery preparedness). The development and implementation of effective pre-impact hazard management actions can significantly reduce reliance on improvised emergency response and improvised disaster recovery actions.

Hazard or Vulnerability Analysis for the Storage and Transportation Scenarios

The Federal Emergency Management Agency[23] recommends that community emergency operations plans (EOPs) be based on an explicit statement of *situation and assumptions* derived from hazard and vulnerability analyses and should also have hazard-specific appendixes that address any distinctive disaster demands imposed by specific hazard agents. However, no one has examined whether EOPs do contain appendixes for the

[22]Prater, C.S., and M.K. Lindell. 2000. The politics of hazard mitigation. *Natural Hazards Review* 1:73-82.

[23]Federal Emergency Management Agency. 1996. *Guide for All Hazard Emergency Operations Planning.* SLG-101. Washington, DC.

appropriate hazards and whether the distinctive demands of these hazards are correctly identified. The available research on local assessments of chemical vulnerability indicates that a significant percentage of local jurisdictions have used the *Emergency Response Guidebook,*[24] rather than the *Technical Guidance for Hazards Analysis*[25] or computer programs such as *ALOHA,*[26] to calculate the vulnerable zones around chemical facilities in their communities.[27] Research is needed to determine if this situation has improved in recent years and, if not, what the impediments are to improving the quality of these analyses.

Research is also needed to develop simple methods of assessing the physical vulnerability of buildings, especially to air infiltration of toxic chemicals. Emergency managers need to be able to determine which areas of their communities have sufficiently low levels of air infiltration that sheltering-in-place is a feasible protective action during a toxic chemical release. There can be significant variability in the air infiltration rates among structures within a neighborhood, which requires extensive sampling of these structures. At present, however, the testing procedures are time consuming and expensive so local emergency managers cannot afford to conduct detailed analyses. Developing simple, reliable methods of assessing air infiltration would overcome this problem.

Research is also needed to better understand the concept of social vulnerability to identify those population segments whose limited resources impede their ability to adopt hazard mitigation measures or to prepare for, respond to, and recover from disasters. Moreover, there is a need to understand the driving forces that determine that level of vulnerability.[28]

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[24]Department of Transportation, Transport Canada, and Secretariat of Transport and Communications. 2000. *Emergency Response Guidebook*. Washington, DC.

[25]Environmental Protection Agency. 1987. *Technical Guidance for Hazards Analysis: Emergency Planning for Extremely Hazardous Substances*. Washington, DC.

[26]National Safety Council. 1995. *User's manual for CAMEO: Computer-aided management of emergency operations*. Chicago, IL.

[27]Lindell, M.K., and R.W. Perry. 2001. Community innovation in hazardous materials management: Progress in implementing SARA Title III in the United States. *Journal of Hazardous Materials* 88:169-194.

[28](a) Cutter, S.L. 2003. The vulnerability of science and the science of vulnerability. *Annals of the Association of American Geographers* 93(1):1-12; (b) Heinz Center. 2002. *Human Links to Coastal Disasters*. Washington, DC: H. John Heinz III Center for Science, Economics and the Environment; (c) Kasperson, J.X., and R.E. Kasperson. 2001. *International Workshop on Vulnerability and Global Environmental Change*. Stockholm: Stockholm Environment Institute, SEI Risk and Vulnerability Programme Report 2001-01, p. 36.

Hazard and Vulnerability Analysis for the Chemical Shortage and Misuse Scenarios

Hazard and vulnerability analysis procedures have been developed for situations in which a chemical is dispersed in the air or water from a point source. Such situations correspond closely to the storage and transportation scenarios. However, hazard or vulnerability analysis procedures are less well defined for situations corresponding to the chemical shortage and misuse scenarios. Thus, research is needed to develop hazard or vulnerability analysis procedures for these types of situations.

Hazard Mitigation

Storage and Transportation Scenarios. Hazard source control both for fixed sites and in transport is currently regulated by the federal government (EPA and U.S. Department of Transportation respectively). Changes to local land use practices and building construction practices can also reduce hazard vulnerability, but these practices are determined by local ordinances—although state mandates have a significant effect on local implementation.[29] Anecdotal evidence suggests that local jurisdictions do little to regulate incompatibilities between chemical facilities and other land uses, especially special facilities such as schools, hospitals, nursing homes, and jails. The federal government could assist, however, by investing in research to assess the benefits (effectiveness in protecting persons and property, usefulness for other purposes) and resource requirements (cost, time and effort, specialized knowledge and skill, interagency cooperation) of alternative land use practices that local jurisdictions could implement to reduce their vulnerability to chemicals. Similar research could help promote the adoption of building construction practices that reduce infiltration of contaminated air into structures near chemical facilities or transport routes — for example, cheaper, more effective methods of weather stripping and other retrofitting of air infiltration barriers.[30] Research should examine the joint

[29](a) Burby, R.J. 2005. Have state comprehensive planning mandates reduced insured losses from natural disasters? *Natural Hazards Review* 6:67-81; (b) May, P.J., and R.E. Deyle. 1998. Governing land use in hazardous areas with a patchwork system. In R. J. Burby (ed.) *Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities.* Washington, DC: Joseph Henry Press. (pp. 57-82).

[30] Lindell, M.K. 1995. Assessing emergency preparedness in support of hazardous facility risk analyses: An application at a U.S. hazardous waste incinerator. *Journal of Hazardous Materials* 40:297-319.

efforts of regulations, incentives, and risk communication on households and businesses and their decision making with respect to such measures.

Chemical Shortage and Misuse Scenarios. Hazard mitigation for the chemical shortage scenario can be achieved by preventing the loss of the production facilities needed to provide critical levels of the required pharmaceuticals. Hazard mitigation for the misuse scenario can be achieved by preventing terrorists from contaminating food and consumer products without being detected. This is achieved by normal industrial security during production, quality assurance or quality control (QA/QC) before packaging, QA/QC during distribution, and redundant security packaging that allows retailers and consumers to recognize package tampering.

Emergency Preparedness

Storage and Transportation Scenarios. Research could improve emergency preparedness in four areas: planning processes; emergency response; training and equipment; and drills, exercises, and incident critiques.

Planning Processes. Improved planning processes can help local emergency planners and emergency responders make the most effective use of their limited time and energy. The Superfund Amendments and Reauthorization Act of 1986 (SARA Title III) prompted the development of a community-wide emergency planning process that was quite consistent with the findings of social science research on emergency planning.[31] This research has begun to develop a comprehensive model of the preparedness planning process but much remains to be learned.[32] One important goal for future research is to better understand the ways in which local emergency management, fire, and police personnel can build community support for chemical emergency preparedness. Another goal is to develop new ways to enhance the effectiveness of interdisciplinary teams in planning, training, and exercising for chemical emergencies.

Emergency Response Functions. Further research is needed on all four of

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[31](a) Drabek, T.S. 1986. *Human System Responses to Disaster: An Inventory of Sociological Findings.* New York: Springer; (b) Tierney, K.J., M.K. Lindell, and R.W. Perry. 2001. *Facing the Unexpected: Disaster Preparedness and Response in the United States.* Washington, DC: Joseph Henry Press.

[32]Lindell, M.K., C.S. Prater, and R.W. Perry. in press. *Emergency Management Principles and Practices.* Hoboken, NJ: Wiley.

the emergency response functions: emergency assessment, expedient hazard mitigation, population protection, and incident management.

Major disasters require emergency managers to rapidly detect dangerous conditions, assess the situation, and decide how to terminate it. Improved detection technology, especially for transportation incidents involving unknown hazard agents could assist in this aspect of emergency assessment.[33] In addition to sensing a release and identifying the agent, detection systems should provide rapid notification of the location at which the release is occurring. Research is also needed to improve incident managers' ability to utilize this information effectively. An improved understanding of the ways in which incident managers assess emergencies might identify judgmental heuristics and biases that impair the accurateness and completeness of these assessments.[34] Once identified, training programs and decision support systems could be designed to overcome these heuristics and biases.

Many, if not most, major emergencies require local officials to initiate protective actions for the population at risk. This requires protective action selection (usually between evacuation and sheltering-in-place), warning, protective action implementation, impact zone access control and security, reception and care of victims, search and rescue, emergency medical care and morgues, and hazard exposure control.[35] However, there is virtually no research on *preparedness* for population protection, or on the extent to which practitioners use the findings of scientific research in developing community preparedness for population protection. For example, sheltering-in-place is sometimes the most appropriate protective action recommendation, but the criteria for choosing between evacuation and sheltering-in-place can be complex and there appears to be no research assessing the adequacy of emergency managers' decision criteria for choosing be-

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[33]National Research Council. 2002. *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism.* Washington, DC: The National Academies Press, pp. 113-116.

[34](a) Baron, J. 2000. *Thinking and Deciding.* New York: Cambridge University Press; (b) Gilovich, T., D. Griffin, and D. Kahneman. 2002. *Heuristics and Biases: The Psychology of Intuitive Judgment.* New York: Cambridge University Press.

[35](a) Lindell, M.K., and R.W. Perry. 1992. *Behavioral Foundations of Community Emergency Planning.* Washington, DC: Hemisphere; (b) Lindell, M.K., C.S. Prater, and R.W. Perry. in press. *Emergency Management Principles and Practices.* Hoboken, NJ: Wiley.

tween these alternatives.[36] Nor is there adequate research on vulnerable zone populations' likely compliance and timeliness in implementing protective action recommendations.[37] Moreover, little research has been conducted on community warning systems since the EPA supported a series of studies after the Bhopal accident.[38] In principle, communities can design the most appropriate warning systems based on the characteristics of the hazards to which they are exposed (especially speed of onset and scope of impact) and the characteristics of the jurisdiction (e.g., population density, wealth). However, no research to date has examined the process by which this takes place. Research on this topic could identify impediments to the development of effective community warning systems and, ideally, stimulate engineering research to overcome these impediments.

Population protection also includes the transmission of warning messages that describe the threat, an appropriate protective action, and sources of additional information. There is a considerable base of research on warnings and risk communication,[39] but there appears to be little or no research on the extent to which practitioners use the findings of this research in developing community emergency preparedness. As previous chapters have noted, appropriate communications can be the key that prevents the consequences of an event from reaching catastrophic levels. Research on preparedness for warning should address the choice of warning sources, warning mechanisms, and warning content and the reasons for choosing them. In addition, research should examine the extent to which emergency managers systematically consider the time required to disseminate warnings and the role of informal warning networks in the dissemination process.

There is a small but important research literature on protective action

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[36](a) Lindell, M.K., and R.W. Perry. 1992. *Behavioral Foundations of Community Emergency Planning.* Washington, DC: Hemisphere; (b) Sorensen, J.H., B.L. Shumpert, and B.M. Vogt. 2004. Planning for protective action decision making: Evacuate or shelter in-place. *Journal of Hazardous Materials* A109:1-11.

[37]Lindell, M.K., and C.S. Prater. 2005. *Critical Behavioral Assumptions in Evacuation Time Estimate Analysis: Examples from Hurricane Research and Planning.* College Station, TX:Texas A&M University Hazard Reduction & Recovery Center.

[38](a) Sorensen, J.H. 2000. Hazard warning systems: Review of 20 years of progress. *Natural Hazards Review* 1:119-125; (b) Sorensen, J.H., and G.O. Rogers. 1988. Local preparedness for chemical accidents: A survey of U.S. communities. *Industrial Crisis Quarterly* 2:89-108; (c) Sorensen, J.H., and G.O. Rogers. 1989. Warning and response in two hazardous materials transportation accidents in the U.S. *Journal of Hazardous Materials* 22:57-74.

[39]Lindell, M.K., and R.W. Perry. 2004. *Communicating Environmental Risk in Multiethnic Communities.* Thousand Oaks, CA: Sage.

implementation that includes some significant advances in modeling distributions of warning and preparation times required for the populace to take protective actions,[40] but recent data are mostly limited to hurricanes.[41] Quantitative data are needed for a variety of incidents to assess warning and preparation time distributions for chemical incidents. In addition, research is needed to assess the extent to which these preparation time distributions are predictable from households' demographic characteristics (e.g., size and age distribution, transit dependence) so that emergency managers can use census data to adjust generic distributions to local conditions.

Quantitative models for computing evacuation time estimates from traffic models are also now available.[42] However, there have been few efforts to validate the models to determine if analysts' assumptions about evacuees' behavior are accurate. One major uncertainty concerns the rate of

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[40]Rogers, G.O., and J.H. Sorensen. 1988. Diffusion of emergency warnings. *Environmental Professional* 10:281-294.

[41]Lindell, M.K., R.W. Perry, and C.S. Prater. 2005. *Organizing Response to Disasters with the Incident Command System/Incident Management System (ICS/IMS).* Taipei: International Workshop on Emergency Response and Rescue.

[42](a) Abkowitz, M., and E. Meyer. 1996. Technological advancements in hazardous materials evacuation planning. *Transportation Research Record* 1522:116-121; (b) Barrett, B., B. Ran, and R. Pillai. 2000. Developing a dynamic traffic management modeling framework for hurricane evacuation. *Transportation Research Record* 1733:115-121; (c) Cova, T.J., and R.L. Church. 1997. Modeling community evacuation vulnerability using GIS. *International Journal of Geographical Information Science* 11:763-784; (d) Cova, T.J., and J.P. Johnson. 2002. Microsimulation of neighborhood evacuations in the urban-wildland interface. *Environment and Planning A.*34(12):2211-2229; (e) Hobeika, A.G., and C. Kim. 1998. Comparison of traffic assignments in evacuation modeling. *IEEE Transactions on Engineering Management* 45:192-198; (f) Lindell, M.K., C.S. Prater, R.W. Perry, and J.Y. Wu. 2002. EMBLEM: *An Empirically-Based Large Scale Evacuation Time Estimate Model.* College Station, TX: Texas A&M University Hazard Reduction and Recovery Center; (g) Lindell, M.K., and R.W. Perry. 2004. *Communicating Environmental Risk in Multiethnic Communities.* Thousand Oaks, CA: Sage; (h) Oak Ridge National Laboratory. 2003. Oak Ridge Evacuation Modeling System: OREMS Version 2.60. Oak Ridge, TN; (i) Safwat, N., and H. Youssef. 1997. *Texas Hurricane Evacuation Time Estimates.* College Station, TX: Texas A&M University Hazard Reduction and Recovery Center; (j) Tweedie, S.W., J.R. Rowland, S.J. Walsh, R.P. Rhoten, and P.I.Hagle. 1986. A methodology for estimating emergency evacuation times. *The Social Science Journal* 23:189-204; (k) Urbanik, T., M.P. Moeller, and K. Barnes. 1988. *Benchmark Study of the I-DYNEV Evacuation Time Estimate Computer Code,* NUREG/CR-4873. Washington, DC:U.S. Nuclear Regulatory Commission; (l) Urbanik, T., M.P. Moeller, and K. Barnes. 1988. *The Sensitivity of Evacuation Time Estimates to Changes in Input Parameters for the I-DYNEV Computer Code,* NUREG/CR-4874. Washington, DC: U.S. Nuclear Regulatory Commission.

traffic flow when the demand on evacuation routes in a risk area exceeds its capacity—especially when queues take many hours to clear.[43] It is important to accurately estimate the duration of the queues but it also is important to know where they are located because queues, inside risk areas are potentially life threatening. Finally, research on preparedness for protective action implementation should address the behavioral parameters that affect the time required to complete an evacuation (see Table 5.1). These variables can have a significant influence on evacuation time estimates, but evacuation analysts appear to be making unfounded assumptions about them in the absence of reliable data.

Research is needed to justify the choice between evacuation and sheltering-in-place during chemical emergencies. Such research will require social scientists to collaborate with transportation planners and engineers on evacuation modeling and with mechanical engineers on shelter-in-place modeling. There is a modest literature on the effectiveness of sheltering-in-place,[44] but virtually no research on people's perceptions of its effectiveness and the logistics of implementation. Emergency managers need to know much more about people's willingness to comply with recommendations to shelter in-place during chemical releases.

There appears to have been no research on preparedness for impact zone access control and security, search and rescue, emergency medical care and morgues, or hazard exposure control. Moreover, there appears to be no research on the ways in which these topics are addressed by local emergency managers in their emergency operations plans, procedures, and training. However, there is some anecdotal information about the utilization of re-

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[43](a) Homberger, W.S., J.W. Hall, R.C. Loutzenheiser, and W.R. Reilly. 1996. *Fundamentals of Traffic Engineering.* Berkeley, CA: University of California Institute of Transportation Studies; (b) Transportation Research Board. 1998. *Highway Capacity Manual, Special Report 209,* 3rd ed. Washington, DC; (c) Urbanik, T. 1994. State of the art in evacuation time estimates for nuclear power plants. *International Journal of Mass Emergencies and Disasters* 12:327-343; (d) Urbanik, T. 2000. Evacuation time estimates for nuclear power plants. *Journal of Hazardous Materials* 75:165-180.

[44] (a) Lindell, M.K., and R.W. Perry. 1992. *Behavioral Foundations of Community Emergency Planning.* Washington, DC: Hemisphere; (b) Sorensen, J.H., B.L. Shumpert, and B.M. Vogt. 2004. Planning for protective action decision making: Evacuate or shelter in-place. *Journal of Hazardous Materials* A109:1-11; (c) Mileti, D.M., J.H. Sorensen, and P.W. O'Brien. 1992. Toward an explanation of mass care shelter use in evacuations. *International Journal of Mass Emergencies and Disasters* 10:25-42.

TABLE 5.1 Evacuation Parameters

Parameter	Data Source
Background data collection	
Emergency Response Planning Area (ERPA) definition	Hazard analysis
Evacuation Route System (ERS) definition	Transportation department
Trip generation	
Size and distribution of the resident population	U.S. Census
Number of persons per residential household	U.S. Census
Size and distribution of the transit dependent resident population	U.S. Census
Number of evacuating vehicles per residential household	Behavioral research
Number of evacuating trailers per residential household	Behavioral research
Size and distribution of the transient population	Local Visitors' Bureau
Number of evacuating vehicles per transient household	Behavioral research
Percentage of residents' protective action recommendation (PAR) compliance/ spontaneous evacuation	Behavioral research
Percentage of transients' PAR compliance/ spontaneous evacuation	Behavioral research
Departure timing	
Percentage of early evacuating residential households	Behavioral research
Percentage of early evacuating transient households	Behavioral research
Residential households' departure time distribution	Behavioral research
Transients' departure time distribution	Behavioral research
Destination/route choice	
Evacuation ultimate destination	Behavioral research
Evacuees' proximate destination/route choice	Behavioral research
Evacuees' utilization of the primary evacuation route system	Behavioral research

search on the reception and care of victims; Mileti, Sorensen and O'Brien's (1992) review of the research on this topic was used as the basis for planning hurricane emergency response in Texas, but primarily because hazards researchers drafted the planning documents for the emergency management agency.

Little or none of the research in incident management has been conducted on *preparedness* for incident management or on the *utilization* of disaster research findings in the development of community emergency operations plans, procedures, or training. Particularly needed is an assessment of the degree to which the adoption of the Incident Command System-Incident Management System[45] (ICS/IMS) has successfully addressed intra- and interorganizational coordination.[46] One of the potential limitations of the ICS/IMS is the lack of explicit attention to the population protection function, especially warning, sheltering-in-place, evacuation, and mass care.[47] Such activities take place away from the incident scene where the operations section chief cannot readily supervise them. Moreover, addition of these functions could overload someone who is already responsible for fire, hazardous materials, rescue, transport, and medical branches. Thus, research is needed to determine when and how to assign the population protection function to the jurisdictional emergency operations center.

Training and Equipment Needs Assessment. A recent review of research on training has called attention to the unique challenges of training for emergency response—including retention of infrequently practiced skills over long periods of time.[48] In addition, the research literature on team

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[45](a) Brunacini, A.V. 1985. *Fire Command.* Quincy, MA: National Fire Protection Association; (b) Brunacini, A.V. 2002. *Fire Command: The Essentials of IMS.* Quincy, MA: National Fire Protection Association; (c) Irwin, R.L. 1989. The Incident Command System (ICS). In E. Auf der Heide (ed.), *Disaster Response: Principles of Preparation and Coordination.* St. Louis, MO: C.V. Mosby Company; (d) Federal Emergency Management Agency. 2004. National Incident Management System (NIMS): An Introduction. Washington, DC. Available at *http://www.fema.gov;* (e) National Wildfire Coordinating Group. 1994. Incident Command System National Training Curriculum. Available at *www.nwcg.gov/pms/forms/ics_cours/ics_courses.htm.*

[46](a) Drabek, T.E., H.L. Tamminga, T.S. Kilijanek, and C.R. Adams. 1981. *Managing Multiorganizational Emergency Responses.* Boulder, CO:University of Colorado Institute of Behavioral Science; (b) Dynes, R. 1977. Interorganizational relations in communities under stress. In E.L. Quarantelli (ed.) *Disasters: Theory and Research.* Beverly Hills, CA: Sage, pp. 49-64; (c) Kreps, G.A. 1989. Future directions in disaster research: The role of taxonomy. *International Journal of Mass Emergencies and Disasters* 7:215-241; (d) Kreps, G.A. 1991. Organizing for emergency management. In Drabek, T.S. and Hoetmer, G.J. 1991. *Emergency Management: Principles and Practice for Local Government.* Washington, DC: International City/County Management Association, pp. 30-54.

[47]Lindell, M.K., R.W. Perry, and C.S. Prater. 2005. *Organizing Response to Disasters with the Incident Command System/Incident Management System (ICS/IMS).* Taipei: International Workshop on Emergency Response and Rescue.

[48]Ford, J.K., and A.M. Schmidt. 2000. Emergency response training: Strategies for enhancing real-world performance. *Journal of Hazardous Materials* 75:195-215.

training has addressed the coordination of individual efforts, distribution of workload, and selection of task performance strategies.[49] None of this research has addressed the Incident Command System as defined by the National Wildfire Coordinating Group (1994)[50] or the Incident Management System. Federal development and dissemination of the National Incident Management System[51] makes it essential to examine the ways in which training research can be adapted to the needs of chemical emergency response.

Drills, Exercises, and Incident Critiques. Federal agencies have provided guidance on drills, exercises, and incident critiques[52] that appears to be derived from practitioner experience. However, there appears to be no scientific research on emergency response organizations' performance of these tasks. This is unfortunate because there is relevant research on individual and team training that is relevant to this problem. For example, Hackman and Wageman (2005)[53] proposed a model of team coaching that contains

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[49] (a) Arthur, W., Jr., B.D. Edwards, S.T. Bell, A.J. Villado, and W. Bennett, Jr. In press. Team task analysis: Identifying tasks and jobs that are team based. *Human Factors*; (b) Campbell, J.P., and N.R. Kuncel. 2002. Individual and team training. In N. Anderson, D.S. Ones, H.K. Sinangil, and C. Viswesvaran (eds.) *Handbook of Industrial, Work and Organizational Psychology*. Thousand Oaks, CA:Sage. pp.278-312; (c) Guzzo, R.A., and M.W. Dickson. 1996. Teams in organizations: Recent research on performance and effectiveness. *Annual Review of Psychology* 47:307-338; (d) Hollenbeck, J.R., D.R. Ilgen, D.J. LePine, J.A. Colquitt, and J. Hedlund. 1998. Extending the multilevel theory of team decision making: Effects of feedback and experience in hierarchical teams. *Academy of Management Journal* 41:269-282; (e) Kraiger, K. 2003. Perspectives on training and development. In W.C. Borman, D.R. Ilgen, R.J. Klimoski, and I.B. Weiner (eds.) *Handbook of Psychology*. Hoboken, NJ: John Wiley. Pp.171-192; (f) Salas, E., and C.A. Cannon-Bowers. 2001. The science of training: A decade of progress. *Annual Review of Psychology* 52:471-499.

[50]National Wildfire Coordinating Group. 1994. Incident Command System National Training Curriculum. Available at *www.nwcg.gov/pms/forms/ics_cours/ics_courses.htm*.

[51](a) Department of Homeland Security. 2004. *National Incident Management System*. Washington, DC; (b) Federal Emergency Management Agency. 2004. National Incident Management System (NIMS): An introduction. Washington, DC. Available at *http://www.fema.gov*.

[52](a) Federal Emergency Management Agency. 2003. *Exercise Design Course*, IS 139. Emmitsburg MD: Emergency Management Institute; (b) National Response Team. 1990. Developing a hazardous materials exercise program: A handbook for state and local officials, NRT-2. Washington, DC: Author.

[53]Hackman, J.R., and R. Wageman. 2005. A theory of team coaching. *The Academy of Management Review* 30:269-287.

relevant concepts. An assessment of the applicability of this model to emergency response organizations is needed.

Misuse Scenario. Emergency preparedness for the misuse scenario can be achieved by prompt epidemiological surveillance that detects and recognizes a common source for seemingly disparate illnesses or deaths. Hazard detection can be followed by prompt action to remove contaminated products from the marketplace and warn consumers to return items from potentially contaminated lots to official collection points.

Recovery Preparedness for the Storage and Transportation Scenarios

Pre-impact recovery planning has been advocated by a number of scholars,[54] but research evaluating its effectiveness is quite limited.[55] Available research indicates that pre-impact recovery planning was associated with faster housing recovery and better integration of hazard mitigation into the recovery process, but much more research is needed to test the generalizability of these results.

Need to Refine the DIM for Chemical Incident Management

There is a need to resolve the apparent conflict between the results of previous disaster research, which support an all-hazards approach, and the increased focus on specific hazards that has emerged in recent approaches to homeland security. Expedient hazard mitigation is arguably specific to a single hazard or group of hazards with similar effects, and emergency assessment arguably also has hazard-specific aspects. However, most aspects of population protection and incident management appear to apply to a wide variety of hazards. Research is needed to determine if this assumption is correct.

How human responses to intentional terrorist events differ from those in response to natural or technological events remains to be determined. There has been much speculation that we cannot use past history to under-

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[54]Schwab, J., K.C. Topping, C.C. Eadie, R.E. Deyle, and R.A. Smith. 1998. *Planning for Post-Disaster Recovery and Reconstruction.* PAS Report 483/484. Chicago, IL: American Planning Association.

[55]Wu, J.Y., and M.K. Lindell. 2004. Housing reconstruction after two major earthquakes: The 1994 Northridge earthquake in the United States and the 1999 Chi-Chi earthquake in Taiwan. *Disasters* 28:63-81.

stand and predict how people would respond to events not previously experienced in this country. However, the likely responses to events such as suicide bombings, releases of biological agents, attacks with radiological dispersion devices, or releases of chemical warfare agents can be studied using careful empirical research before such disasters occur. Preliminary findings from the large number of post-9/11 investigations and studies of the 1993 World Trade Center and Oklahoma City bombings suggest that some types of behavior are similar to those observed in other large-scale disasters. Thus, the absence of panic and the large amount of altruistic behavior in these incidents come as no surprise. Other types of behavior, such as changes in travel behavior and product purchases, have not been studied in connection with disasters but have been observed in connection with stigmatized products such as cyanide-contaminated bottles of Tylenol and Alar-tainted apples. It is critical that comparative research efforts be made to document and understand the variations in human response to a wide range of hazards and social conditions if inappropriate negative responses and their consequences are to be mitigated.

Research should be conducted to develop a realistic model of the effectiveness of pre-impact hazard management actions in reducing the physical and social impacts of a chemical incident. Conventional risk analyses typically calculate the area exposed to a specified chemical concentration, the number of people that would be exposed, and occasionally, the number of casualties that might be expected from a given release magnitude. Such analyses are useful for site-specific analyses, but rational priorities for S&T investments in pre-impact hazard management actions should be guided by a comprehensive model that can assess the expected reduction in physical (casualties and damage) and social (psychological, demographic, economic, and political) impacts of chemical incidents given one or more specific hazard mitigation, emergency response, or disaster recovery actions. For example, analysts should be able to specify the characteristics of a storage and transportation scenario (e.g., quantity of toxic chemical, meteorological conditions, population distribution) and estimate the physical and social impacts under existing conditions of hazard mitigation (i.e., building air infiltration rates), emergency response (e.g., warning, evacuation, medical transport and care), and recovery (debris removal or contamination cleanup, resource management, business resumption). Analysts could then test the effects of alternative levels (e.g., moderate investment, substantial investment) of the model parameters to identify the pre-impact hazard management actions that provide the greatest reduction in physical and social impacts. A well-developed model should be able to identify which policies provide the greatest reduction in disaster impacts. In addition, it should be able to determine how much improvement in hazard mitigation, emergency preparedness, and disaster recovery actions can be expected from a given level of S&T investment.

RISK PERCEPTION

Traditional risk assessment focuses on losses that are often measured in monetary units. Risk perception is concerned with the psychological and emotional factors that have been shown to have an enormous impact on behavior. In a set of path-breaking studies begun in the 1970s, Paul Slovic, Baruch Fischhoff, and other psychologists began measuring laypersons' concerns about different types of risks. These studies showed that those hazards of which the person had little knowledge, and were also highly dreaded, were perceived as being the most risky. The general finding that laypersons see the world differently from the scientific community also raised a set of questions as to the nature of the decision-making process for dealing with risks.

The problems associated with risk perception are compounded because of the difficulty individuals have in interpreting probabilities in making their decisions.[56] In fact, there is evidence that people may not even want data on the likelihood of an event occurring.[57] If people do not think probabilistically, how do they make their choices? There is now a large body of evidence that individuals' risk perceptions are affected by judgmental biases. The availability heuristic is one of the most relevant ones for dealing with extreme events. Here people estimate the likelihood of an event by the ease with which they can imagine or recall past instances.[58] In cases where the information on an event is salient so that individuals fail to take into account the base rate, there will be a tendency by many to overestimate the probability of the event occurring. Following the terrorist activities of September 11th, many people refused to fly because they perceived

[56]Kunreuther, H., N. Novemsky, and D. Kahneman. 2001. Making low probabilities useful. *Journal of Risk and Uncertainty* 23:103-120.

[57]Huber, O., R. Wider, and O. Huber. 1997. Active information search and complete information presentation in naturalistic risky decision tasks. *Acta Psychologica* 95:15-29.

[58]Tversky, A., and D. Kahneman. 1973. Availability: A heuristic for judging frequency and probability. *Cognitive Psychology* 5:207-232.

the chances of being on a hijacked plane to be extraordinarily high even though it could be argued that the likelihood of such events occurring in the future was much lower given increased vigilance and added protection by the federal government.

Other factors besides probability and consequences influence choices under risk and uncertainty. There is a growing body of evidence that affect and emotions play an important role in people's decision processes.[59] These factors play a particularly important role when individuals face a decision that involves a difficult trade-off between attributes or where there is ambiguity concerning what constitutes a "right" answer. In these cases, people often appear to resolve tasks by focusing on those cues that send the strongest affective signals. In other words, rather than basing one's choices simply on the likelihood and consequences of different events, individuals are also influenced in their choices by emotional factors such as fear, worry, and love. It is also important to note that risk perception varies by previous experiences (e.g., prior exposure to an event), gender, race or ethnicity, income, and education, among other variables.

IMPACT OF INTERDEPENDENCIES OF THE CHEMICAL SUPPLY CHAIN ON RISK-REDUCING MEASURES

Weak links in the safety and security of the chemical infrastructure and supply chain networks can compromise the entire system. Given the decentralized nature of many parts of the supply chain due to distributed ownership and control, it may be difficult to coordinate risk-reducing measures across the system. Appropriate cost-effective measures must be identified to reduce risks from terrorism when there are interdependencies in the system. Strategies involving private-public partnerships can be developed to encourage firms to adopt these measures. These strategies include a combination of such measures as economic incentives, third-party inspections, insurance, and well-enforced regulations and standards.

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[59](a) Slovic, P., M. Finucane, E. Peters, and D. MacGregor. 2002. The affect heuristic. In T. Gilovich, D. Griffin, and D. Kahneman (eds.), *Intuitive Judgment: Heuristics and Biases.* Cambridge, UK: Cambridge University Press; (b) Loewenstein, G., E. Weber, C. Hsee, and E. Welch. 2001. Risk as feelings. *Psychological Bulletin* 127:267-86; (c) Hsee, C., and H. Kunreuther. 2000. The affection effect in insurance decisions. *Journal of Risk and Uncertainty* 20:141-159.

One reason that units in the supply chain are reluctant to incur the costs of investing in risk-reducing measures on their own is that even after doing so they may be adversely impacted by other firms in the system that fail to adopt similar measures. An effective investment by any firm or unit in the supply chain to reduce the likelihood and consequences of a disruption is often a costly investment. When there are interdependencies between units in the system there is less incentive for one unit to invest in protective measures if the other units have not taken similar action. Even if modifications of a single unit can reduce the chances of a disruption to the supply chain caused by its own operations, it can still be adversely affected by a second unit that did not undertake similar protective measures. In other words, in an interdependent system, investing in security buys a single unit less protection when there is the possibility of disruption from another unit. In fact, in an interdependent system, reducing vulnerabilities in one area might inadvertently increase vulnerability in another since the terrorists will conceivably turn to attacking weak links when choosing where to utilize their resources. There is a need to utilize existing institutional structures such as trade associations to promote coordination among units in the system. One could also utilize economic incentives such as subsidies to encourage certain activities and taxation to discourage others that will lead to win-win situations for everyone in the system.

The more units in the network that do not invest in security, the less incentive will any specific unit in the system have to invest in protection. In other words, if one wants to protect the entire supply chain it requires coordination between all units in the system through either the private sector or some type of public sector intervention. That is, weak links may lead to suboptimal behavior by everyone. By coordinating the actions of all units in the supply chain, each firm will be better off because its expected profits will increase and society will be better off because the risks of disruption will be lower.[60]

Tipping and Cascading Behavior

There may be ways of inducing tipping and cascading so that the welfare of every component in the supply chain is improved. *Cascading* refers

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[60] Kunreuther, H., and H. Geoffrey. 2003. Interdependent security. *Journal of Risk and Uncertainty, Special Issue on Terrorist Risks* 26:231-249.

to a domino effect. If one unit invests in protection, then there is an incentive for a second unit to do the same, which leads a third unit to incur these costs and so on. The concept of *tipping* (from the tipping of a scale) refers to many others in the supply chain simultaneously investing in security measures because one or more units in the supply chain have done so. In taking these actions, those units reduce the possibility that the supply chain will be disrupted and hence provide an economic incentive for others to follow suit.

Units or firms in any supply chain are heterogeneous; having different risks and costs associated with their activities. In the case of the chemical supply chain some units may have a much higher risk than others of causing a failure in the entire system through an accident or other disruption of its activities. These units are referred to as *weak links* in the supply chain. It has been shown that one unit in the supply chain may occupy such a strategic position that if it changes from not investing to investing in protection, all other units will find it in their interests to follow suit. In this case, this single unit will *tip* the entire system. [61]

Even if no single unit can exert such leverage, a critical mass may have the ability to do so. To best effect protection of the entire supply chain, units that could have the greatest negative impact on others in the system should be encouraged to invest in protective behavior, not only to reduce the possibility of losses to themselves and others, but also to induce other units to follow suit. Tipping suggests that it is particularly important to identify and then persuade these key players to manage risks more carefully through economic incentives (e.g., subsidies or fines). Working with them may be a viable substitute for working with everyone in the supply chain.

Tipping and cascading behavior has been documented in many contexts where there is a sudden change from one equilibrium to another due to the movement of a few agents (e.g., the sudden change in the demographics of a neighborhood).[62]

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[61]Heal, G., and H. Kunreuther. In press. You Can Only Die Once: Interdependent Security in an Uncertain World. In H.W. Richardson, P. Gordon and J.E. Moore II (eds.), *The Economic Impacts of Terrorist Attacks*. Cheltenham, UK: Edward Elgar.

[62]Schelling, T. 1978. *Micromotives and Macrobehavior*. New York:Norton.

Strategies for Reducing Interdependent Risks

The economic incentive for any individual unit in the supply chain to invest in risk-reducing measures is dependent on others taking similar actions. This situation resembles the familiar dilemma of the commons where there is no economic incentive for any individual or firm to take steps to reduce a risk, but if everyone adopted these measures, all would be better off. In these situations some type of intervention is required to address this problem of interdependent security (IDS). This intervention could be by a coordinating unit in the private sector, such as a trade association, or through well-enforced regulations or standards coupled with insurance and third-party inspection.

Role of Trade Associations

A trade association can play a coordinating role by stipulating that any member has to follow certain rules and regulations, including the adoption of security measures. For example, the National Association of Chemical Distributors (NACD) has developed a code of responsible distribution, has mandated third-party auditing of code compliance, and has actually terminated membership for noncompliance. Other chemical industry associations such as the American Chemistry Council (ACC), Synthetic Organic Chemical Manufacturers Association (SOCMA), American Petroleum Institute (API), and National Petrochemical and Refiners Association (NPRA) have member codes of conduct and can also play key roles in this regard.

Role of Third-Party Inspections, Insurance, and Well-Enforced Regulations and Standards

Well-enforced regulations and standards that require all units in the supply chain to undertake risk-reducing measures can play a role similar to that of trade associations. One example of such a regulation is Section 112(r) of the Clean Air Act Amendments. The passage of Section 112(r) of the Clean Air Act Amendments (CAAA) of 1990 created two new federal regulatory programs aimed at preventing releases of hazardous chemicals—the Occupational Safety and Health Administration (OSHA) Process Safety Management Standard and the EPA Risk Management Program. The OSHA program, enacted in 1992, required facilities containing large quantities of highly hazardous chemicals to implement accident prevention and emergency response measures to protect workers. The EPA Risk Management Program regulation published in 1996 went beyond the OSHA program by requiring facilities to perform a hazard assessment and to submit a summary report to EPA by June 1999 called the Risk Management Plan.[63]

The EPA and other regulatory agencies have been searching for other alternatives to their centralized procedures to implement regulatory obligations due to their limited personnel and funds. Third-party inspections coupled with insurance protection can encourage decentralized units in the supply chain to reduce their risks from accidents and disasters and lead to a high compliance level. Such a management-based regulatory strategy shifts the focus of decision making from the regulator to individual units who are now required to do their own planning to meet a set of standards or regulations.[64]

The rationale behind using third parties and insurance to support regulations can be stated in the following way. As pointed out above, one of the biggest concerns of a regulatory agency is that it doesn't have enough resources to audit all firms in the industry. By coordinating with the private sector, the number of audits the agency must perform can be reduced.

Third-party inspection in conjunction with private insurance is a powerful combination of two market mechanisms that can convince many firms of the advantages of implementing security measures to make their operations safer. If insurance companies provide lower premiums to companies that have passed audit by a recognized third party, firms will have incentives to voluntarily adopt security measures. Federal regulatory agencies can then focus their audits on firms that have not applied or qualified for the discount. Those units taking action can encourage the remaining ones to comply with regulations to avoid being caught and fined. This is another form of tipping behavior.

Without some type of inspection, low-risk units who have adopted risk-reducing measures cannot credibly distinguish themselves from high-

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[63]Belke, J. 2001. Chemical accident risks in U.S. industry—A preliminary analysis of accident risk data from US hazardous chemical facilities. *Proceedings of the 10th International Symposium on Loss Prevention and Safety Promotion in the Process Industries*. Stockholm, Sweden: Elsevier Sciences.

[64]Coglianese, C., and D. Lazer. 2003. Management-based regulation: Prescribing private management to achieve public goals. *Law and Society Review* 37(4):691-730.

risk units for regulators. However, if regulators coordinated with the private sector to delegate part of the inspection process through insurance companies and certified third-party inspectors, a channel would exist through which the low-risk units can distinguish themselves and avoid government audit. If a unit chooses not to be inspected by certified third parties, it is more likely to be perceived as high-risk rather than low-risk and is more likely to be audited by regulators. In this way, the number of audits needed is reduced because units that have received seals of approval from private third-party inspectors are known.[65]

As demonstrated in the work of the National Transportation Safety Board (NTSB), the U.S. Chemical Safety and Hazard Investigation Board (CSB), and the 9/11 Commission, an effective system will also independently and publicly investigate when catastrophic failures occur. Investigations examine the root and contributing causes, including the sufficiency of policies, practices, and oversight in the private and public domains. Future investigations should include efforts to gather data about interdependent security.

Opportunities to Better Address Interdependent Security

The model of interdependent security[66] can be better tailored to the needs of the chemical infrastructure. The following open issues need to be addressed for a better understanding of the challenges associated with IDS issues and the management of risk in the chemical sector.

Deciding whether to invest in security normally involves considerations over a period of time since there is an investment cost that needs to be compared with the benefits over the life of the protective measure. This is not currently accounted for in the IDS model.

There is a growing literature in behavioral economics suggesting that individuals make choices in ways that differ from the rational model of

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[65](a) Collins, Larry, James C. Belke, Marc Halpern, Ruth A. Katz, Howard C. Kunreuther, and Patrick J. McNulty. 2002. The insurance industry as a qualified third party auditor. *Professional Safety* 47(4):31-38; (b) Kunreuther, H., P. McNulty, and Y. Kang. 2002. Improving environmental safety through third party inspection. *Risk Analysis* 22(2):309-318.

[66] Kunreuther, H., and H. Geoffrey. 2003. Interdependent security. *Journal of Risk and Uncertainty, Special Issue on Terrorist Risks* 26:231-249.

choice.[67] Many individuals are not willing to invest in security for a number of reasons that include myopia, high discount rates, and budget constraints. Others take action because of anxiety and worry. These issues need to be considered when developing more realistic models of choice.

The possibility of an attack on any unit in the system is likely to be influenced by what protective measures it has taken. Hence, these probabilities should be treated as *endogenous*. In the case of the chemical supply chain, terrorists are more likely to focus on targets that are less protected.[68] Future research should examine how changes in endogenous probabilities impact IDS solutions and the appropriate strategies for improving the performance of individual units as well as the operation of the entire chemical supply chain.

Economic studies to explore the interdependencies of the supply chain, determine how these impact decision making on security measures, and determine the least secure links in the chain is appropriate. DHS's National Assets Database and its ongoing Risk Analysis for Critical Assets Protection (RAMCAP) analysis should be useful in identifying units that represent weak links in the security of the chemical supply chain.[69]

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[67]Kahneman, D., and A. Tversky. 2000. *Choices, Values and Frames.* New York, NY: Cambridge University Press.

[68]Kunreuther, H., and H. Geoffrey. 2003. Interdependent security. *Journal of Risk and Uncertainty, Special Issue on Terrorist Risks* 26:231-249.

[69]The committee did not have access to the National Assets Database or to the results of the RAMCAP exercise.

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Science and Technology Investment to Protect the Nation's Chemical Infrastructure: Findings and Recommendations

In any complex undertaking there is no such thing as zero vulnerability, but vulnerabilities can always be reduced—often at increasing incremental cost. Thus, any action must balance the cost of reducing vulnerabilities against the potential benefits from this action. The chemical infrastructure is a vast and complex interdependent system. By its very nature this industry will always include an element of vulnerability because it regularly produces, uses, and transports hazardous materials. The current system of safety and security in the chemical sector has evolved through a multitude of stages of rebalancing risks as new knowledge is gained and as situations evolve. The findings and recommendations in this chapter are intended to provide guidance and rationale for effective research and development investments that offer the best short- and long-term promise for mitigating the vulnerabilities presented to the nation by potential terrorist attack on the chemical infrastructure.

The major findings and recommendations in this report address the vulnerabilities associated with the chemical infrastructure in general. Other government and private sector efforts are developing site-specific vulnerability assessments and risk assessments that account for site-specific factors (such as the amount of chemical on a site, size of potentially affected population at a site, etc.) that might point to where the findings and recommendations of this report should be most rapidly implemented.

Responding to risk and addressing vulnerabilities is an ongoing process that must be calibrated to the evolving nature of the industry and the threats to its safe operation. The actions outlined in this chapter are those most appropriate at this time. The framework and methodology to address vulnerabilities presented in the earlier chapters offer an ongoing means by which new actions can be identified and taken over time.

MAJOR FINDINGS

Toxic, flammable, and explosive materials present the greatest risk of catastrophic incident. In the absence of specific threat information, it will be most appropriate to invest in mitigation and preparedness for general classes of vulnerabilities.

Absent any specific intelligence information, among chemicals having toxic, explosive, or flammable properties, analysis indicated little benefit in differentiating one specific chemical from another for the purposes of determining research and development needs for securing the chemical infrastructure. Using the example of highly toxic chemicals, consequences of a release depend on so many event-specific variables that it is possible that a release of one toxic material could actually lead to more casualties than a similar-sized release of another more toxic material under different circumstances. Furthermore, measures can be taken to mitigate the potential for and consequences of *any* large volume toxic release. During the analysis of the chemical categories listed in Chapter 3, it was determined that by focusing on general classes of vulnerabilities (i.e., chemical properties) within chemical categories, instead of on specific chemicals, more appropriate guidance for science and technology investments could be given.

By analogy with past accidents involving the chemical industry, it is possible that a single terrorist incident involving the chemical infrastructure could result in catastrophic loss of life or injuries.

This report adopts the definition of catastrophic incident outlined in the Department of Homeland Security's *National Response Plan*—one that "results in large numbers of casualties and/or displaced persons, possibly in the tens of thousands." In part due to lack of access to the results of off-site consequence models, this report discusses scenarios based on historical chemical incidents that serve as existence proofs (but not necessarily upper bounds) for the possible consequences. Using this approach it is easy to determine that a single chemical event could cause catastrophic casualties. For example, approximately 4,000 people died in the immediate aftermath of the methyl isocyanate gas leak from the Union Carbide India Limited Bhopal plant in December 1984.[1] Injuries have been estimated to range from 200,000 to 500,000 and contributed to an accumulation of 15,000 to 20,000 disaster-related deaths in subsequent years, based upon elevated mortality rates among those hundreds of thousands of injured people.[2] In this country, an explosion involving 2,300 tons of ammonium nitrate in a Liberty ship at a loading dock in Texas City, Texas, on April 16, 1947 cascaded into widespread destruction of nearby petroleum refineries, chemical production facilities, and another fertilizer Liberty ship ultimately claiming nearly 600 lives and causing approximately 3,500 injuries—America's worst chemical catastrophe.[3] On September 21, 2001, a huge explosion tore through the AZF (Azote de France) fertilizer factory in Toulouse, France when nearly 400 tons of ammonium nitrate detonated causing extensive physical damage including a 50-meter-wide, 10-meter-deep crater; 500 uninhabitable homes; and more than 27,000 damaged buildings.[4] Casualties from this incident include the loss of 30 lives and approximately 10,000 injuries, and resulted in the medical treatment of more than 14,000 persons for posttraumatic stress.

The economic effects of a single terrorist incident involving the chemical infrastructure could be significant, but multiple terrorist events would be required to achieve nationally catastrophic economic consequences.

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[1]Precise numbers of dead and injured are unknown. The approximation of 4,000 dead was made in 1999. Other estimates include 30,000 permanently or totally disabled, 20,000 temporary cases, and 50,000 minor injuries. Frank Lees. 1996. *Loss Prevention in the Process Industries* 3:A5.1-A5.11.

[2]Dhara, V. R., and R. Dhara. 2002. The Union Carbide disaster in Bhopal: A review of health effects. *Archives of Environmental Health* 57(5):391-404.

[3]See the following references for more information: (a) Minituglia, Bill. 2003. *City on Fire: The Forgotten Disaster that Devastated a Town and Launched a Landmark Legal Battle.* New York: HarperCollins Press; (b) Stephens, Hugh W. 1996. *The Texas City Disaster*, 1947. Austin, TX: University of Texas Press; (c) *http://www.chron.com/content/chronicle/metropolitan/txcity/*; (d) *http://sdsd.essortment.com/texascityexplo_rkvi.htm.*

[4]For more information about the Toulouse incident see the following references: (a) Dechy, N., T. Bourdeaux, N. Ayrault, M-A. Kordek, and J-C. Le Coze. 2004. First lessons of the Toulouse ammonium nitrate disaster, 21st September 2001, AZF plant, France. *Journal of Hazardous Materials* 111:131-138; (b) Dechy, N. and Y. Mouilleau. 2004. Damages of the Toulouse disaster, 21st September 2001. In *Loss Prevention and Safety Promotion in the Process Industries*, 11th International Symposium, Prague; (c) *http://www.uneptie.org/pc/apell/disasters/toulouse/home.html; (d) http://www.environmenttimes.net/article.cfm?pageID=131*; (e) *http://www.icem.org/update/upd2001/upd01-68.html.*

The chemical industry is quite diverse, with redundancies that mitigate the effects of loss of production due to major shutdowns. Where stockpiles do not exist, market forces quickly compensate for loss of production by increased production at another facility of the same or a different company, or by temporary substitution in industrial processes of another chemical with similar properties.

Although a single incident might not result in a nationally catastrophic economic loss, such an incident could result in changes to business and manufacturing processes across the industry, either voluntarily or through regulation. The costs associated with such changes could be significant to individual companies and to local economies, but will not have a major impact on the national economy.

Multiple attacks on the chemical infrastructure may not be immediately recognized as such. Prompt recognition and communication that an incident is an actual case of terrorism and may be part of a series of attacks offers the best opportunity to take actions that may limit the consequences of such attacks.

Recognizing that an attack is part of a larger coordinated effort may be hampered if incidents are widely dispersed, involve different types of attacks, or otherwise present challenges to recognizing a larger pattern, particularly if communication between affected parties is significantly impeded. Therefore, rapid analysis and communication is needed so that heightened surveillance could prevent attacks at subsequent locations.

Public response is significant in determining the consequences of attack on the chemical infrastructure.

Public response to any act of terrorism in this country involving the chemical infrastructure will undoubtedly be significant and could invoke both positive and negative consequences. While the impact of a terrorist incident in itself may be linear (that is, the loss of life and injury will be related directly to the size of a chemical release within a given category of chemicals), there may be significant nonlinear social consequences of the incident. These consequences could significantly affect sectors of the economy, such as the negative impact on the travel and airline industries after September 11th. It may also impact public morale, affect the level of trust and confidence in the government's ability to protect its citizens, and exacerbate feelings of vulnerability leading to social (sociological) and psychological effects. Conversely, a well-informed general population that is adequately prepared for such events could decrease negative consequences and unnecessary casualties.

Accurate information analysis and communication before, during, and after an event between parties responsible for response and to the public may be the best short-term means to mitigate the possible consequences of an event.

The scenarios discussed in Chapter 4 demonstrate the importance of communication in determining the outcomes from any disruption of the chemical infrastructure. Chapter 5 points to the importance of communication in both pre-impact hazard management and emergency response and recovery. Effective communication response consists of several components:

- Acquiring reliable data—In an emergency, this includes reducing data errors and ambiguity to the greatest extent possible;
- Converting the data into integrated information and conclusions;
- Deciding on and communicating appropriate actions; and
- Communicating promptly to the public in an accurate, comprehensible, and believable fashion.

The perception of disasters sometimes escalates as a consequence of a breakdown in the communication process. Conversely, a well-informed public can often take action to minimize the effects of a disaster. Information must reach the end users in a comprehensible and useful form; it must be perceived by them as relevant to their situation (e.g., individuals need to be made aware and recognize their hazard risk and potential outcomes); end users must have the capacity and the necessary resources to use this information to better prepare, respond to, and recover from a hazard or disaster situation.[5]

Near-term benefits can be obtained from research efforts directed toward enhancing emergency preparedness, emergency response, and disaster recovery. This

[5](a) Rodríguez, H., W. Diaz, and B. Aguirre. 2004. Communicating Risk and Warnings: An Integrated and Interdisciplinary Research Approach. University of Delaware, Disaster Research Center, Preliminary Paper No. 337; (b) Lindell, M.K., and R.W. Perry. 2004. *Communicating Environmental Risk in Multiethnic Communities.* Thousand Oaks, CA: Sage.

offers an immediate means to mitigate the effects of a terrorist attack on the chemical infrastructure.

MAJOR RECOMMENDATIONS

DHS should support research directed toward enhancing emergency preparedness, emergency response, and disaster recovery.

Through study of past events, social science research has derived significant understanding of the components required to prepare a community or a populace for hazardous events and to effectively respond to and recover from those events. Efforts to increase this knowledge and to expand its use in practice can rapidly enhance our capacity to mitigate the effects of a chemical event. This could, in turn, make the chemical infrastructure a less attractive target for terrorists. It has the further benefit that such efforts are "dual use"—of near or equal value in the case of a chemical accident. Areas that could be addressed include

- Means to promote community-level hazard mitigation practices, such as land use regulation (e.g., buffer zones and density limits), building construction practices, incentives, and risk communication;
- Factors that promote adoption of more effective emergency preparedness and recovery preparedness;
- The extent to which existing research findings are implemented in local emergency operations, plans, procedures, and training;
- Development of better models to guide protective action decision making in emergencies (i.e., choosing between evacuation and sheltering-in-place), and other aspects of incident management;
- Adequacy of training and exercises for disaster response;
- Understanding how appointed and elected officials and the populace interpret information about hazards and perceive risks; and
- Better understanding of social vulnerability (i.e., identifying those segments of the population whose resources or abilities impede their adoption of hazard mitigation measures or their capacity to prepare for, respond to, or recover from disaster).

DHS should explore ways to enable rapid analysis and communication of data for decision making and communication to the public during and after an emergency.

Effective emergency response depends on the rapid analysis of information received in a crisis to determine its relevance and accuracy. This information must also be communicated rapidly and accurately to all necessary parties involved in decision making, and then integrated into the decision making process to determine an effective response. This is especially true in a chemical attack because event-specific conditions such as the type of chemical, quantity of material, and release location will be critical to determining the appropriate course of action. Research to determine the most critical information to be communicated between responders and to the public, and the means to gather and disseminate that information, can result in a rapid improvement in emergency response capabilities. Such research would be universally applicable to all chemical emergencies—independent of the type of incident or chemical involved.

In investing in and utilizing behavioral and social science research, DHS should give particular attention to understanding and preparing for the societal response that will occur following a major chemical incident.

The American public has long been recognized to be apprehensive about chemicals. Public authorities will need an understanding of social amplification and attenuation if they wish to successfully manage the aftermath of a chemical attack. Research can support the development of specific guidelines for limiting, and even mitigating, consequences by stimulating a positive public response and preventing negative social amplification. Community members and end users should be actively engaged in identifying their vulnerabilities, disaster planning and management, development of technology, and the communication process. The combination of engaging the end users and gaining a better understanding of the forces that cause social amplification or attenuation can effectively enhance the response to an event.

DHS should support research to extend the applicability of current disaster impact models to chemical events.

As noted in Chapter 5, the Disaster Impact Model (DIM) and similar models presented here have been generalized from research on storage and transportation scenarios to the conditions that would exist in the chemical misuse and chemical shortage scenarios. Despite the apparent applicability of the model to the latter two scenarios, further research is needed to confirm that the model's assumptions and relationships are valid in these situations. Previous disaster research supports an all-hazards approach, in contrast to the focus on specific hazards that has emerged in recent approaches to homeland security. Furthermore, there is speculation, but little research, on whether human responses to intentional terrorist events differ significantly from responses to natural disasters or accidents. Such incongruities between current disaster models and current security concerns need to be identified and examined to determine what, if any, changes are required to our current understanding of mitigation preparedness, response, and recovery.

DHS should support research to determine the combinations of incentives and disincentives that would best encourage the private sector to invest in safety and security. This will require research to identify the nature of the interdependencies and weak links in the supply chain and consideration of public-private partnerships to encourage voluntary adoption of protective measures by the weakest links in the chain.

Due to the decentralized nature of many parts of the chemical supply chain, coordinating risk reduction measures across the system may prove difficult. To adequately integrate these risk reduction methods into such a decentralized industry, effort should be expended to identify those places within the chemical infrastructure where interdependencies exists and to understand the need to incorporate risk reduction techniques in these areas.

DHS should develop new or enhance existing cooperative links and collaborative investment strategies with other appropriate government agencies and stakeholders in the community and in the private sector as it seeks to encourage security investments. This would help ensure that efforts to mitigate vulnerabilities are developed in a balanced manner. The coordination of regulation with a system of insurance and third-party inspection, as discussed in Chapter 5, is one such example. The effects of hazard insurance on both individual and corporate decision making could also be fruitfully examined.

DHS should support research and development to foster cost-effective, inherently safer chemistries and chemical processes.

The most desirable solution to preventing chemical releases is to reduce or eliminate the hazard where possible, not to control it. This can be achieved by modifying processes where possible to minimize the amount of hazardous material used, lower the temperatures and pressures required, replace a hazardous substance with a less hazardous substitute, or minimize the complexity of a chemical process.[6]

Many of the advances required to develop practical alternatives to today's chemicals and chemical processes are fundamental and pre-competitive.[7] The economic incentives for industrial funding are frequently absent, which leads to the need for either a government investment in research or government-provided financial incentives for industrial investments. Inherently safer chemistry such as process intensification, "just-in-time" chemical manufacturing, and the use of smaller-scale processes offers the potential for improved safety at chemical facilities. While applications show promise and have found use within the chemical industry, these applications at present are still quite limited in scope.

As a central element of a longer-term research program, DHS should seek ways to improve the safety and security of chemical storage in both fixed facilities and transportation.

A container holding significant quantities of a hazardous chemical provides an obvious terrorist target. While efforts to strengthen existing containers against intentional rupture are ongoing, there may be opportunities to fundamentally change the means by which hazardous chemicals are stored. For example, methods to store chemicals in adsorbents are currently available but are generally limited to small quantities of chemicals. Research could seek to enable use of adsorbents at the cylinder scale and also to use such storage methods for larger volumes involved in truck or rail shipments or on-site storage. Other possibilities for fundamental change in storage include low-pressure storage (which would reduce the release rate given an unintended rupture) or underground storage technologies (which would reduce the storage tank profile presented to terrorists).

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[6]See the following web site for more information: *http://www.ehw.org/Chemical_Accidents/CHEM_InherentSafety.htm.*

[7]Pre-competitive research is research that is sufficiently fundamental in its nature that companies are not adverse to their competitors having equal access to the results (i.e., it requires significant research investment to reach the development stage).

DHS should invest in S&T to enhance real-time monitoring of breaches in containment, the chemical infrastructure and any disruptions to it, and any resulting consequences of an event.

The near-term objective of enhancing emergency response effectiveness can be furthered through efforts to develop reliable detection techniques that can be widely distributed, are easy to use, and would give accurate results quickly and clearly. These can aid in "early warning" of chemical releases to catch them before they become catastrophic and would aid in decision making and response, prevention of catastrophic release, or more timely and effective emergency response if the information reaches Emergency Operations Centers (EOCs) in a timely manner.

In research and development for chemical sensors, DHS should focus on furthering technologies that are relatively inexpensive to deploy and easy to use.

As it pursues sophisticated technologies for security monitoring, DHS should not neglect lower-technology solutions, such as inventory audits and inspections.

Using inventory controls as a means to quickly identify theft of hazardous chemicals may provide a fundamental means to prevent a terrorist attack. This capability may prove difficult if not impossible to mimic with sensor technology. Investments aimed at improving compliance with such procedures would be appropriate.

DHS should support the development and application of robust models to predict off-site consequences of chemical events and ensure that the type of model used is appropriate to the situation.

As shown in Chapter 3 and 4, the presence and use of toxic chemicals create vulnerabilities and could cause catastrophic casualties. Effective predictive models could greatly reduce these vulnerabilities and improve emergency planning and response. Different levels of accuracy and precision are needed for different levels of emergency planning and emergency response. The accuracy and precision of situational models and consequence analysis currently in use must be better understood. While the physics of a hazardous plume release can be described using models, the effect on populations is not yet well characterized. Limitations in understanding of the toxic effects of many substances, and in the understanding of the dose-response relationship of hazardous chemicals over time, especially for vulnerable populations such as children, the elderly, and the poor, limit current capacity to model casualties. Further efforts will be needed to understand the dispersion and toxicity of chemical mixtures. Furthermore, the reliance of early security risk assessments on the outputs of emergency planning efforts such as the Risk Management Plans submitted to the U.S. Environmental Protection Agency (EPA) has led to misimpressions of the potential consequences of individual events. While such data may have been useful for initial screening, they have also led to significant confusion and alarm among various decision makers and the public. Better, more appropriate data should be used, and clear explanations of the change should be provided to different stakeholders.

When considering investments to prevent or mitigate vulnerabilities, DHS should complete an overall risk assessment that would consist of analyzing the combination of vulnerability, threat or likelihood, and consequence of an event.

While the consequences of a terrorist attack on the chemical infrastructure are of significance to the population affected, there is no reason to deviate from the principles and approach of good risk assessment and management decision making when prioritizing investments to mitigate these consequences. Each assessment should consider a realistic scenario and its vulnerabilities, likelihood of occurrence, and consequences if it were to occur. The scenario should be processed through a series of tests to assess if it can be significantly disruptive or catastrophic. These tests should consider loss of life, economic impact, and the ability of state and local government to respond to the event and should also consider the impact of social amplification. This should be followed by an analysis to assess the trade-off between expected benefit and cost of the proposed solution.

CONCLUSION

The findings and recommendations listed in this report emphasize the importance of the development of new technology and investment in current technology and also highlight the need to combine this technology with effective communication strategies, reliable and effective mitigation techniques, and preparedness and response strategies. This combination is needed to minimize the possibility of a terrorist attack and its effects or consequences.

When confronting the potential for terrorist attack, it is essential to constantly reassess both the progress being made and the possibility of unintended consequences when implementing a technology "solution." The threat from terrorism is not static, and it is not unreasonable to assume that terrorist tactics will evolve with emerging technologies designed to defeat their threat. Some strategies to address terrorism reduce the chance of a successful attack, some reduce the consequences of such an incident, and some relocate the vulnerability—that is, these strategies may reduce the chance of direct casualties, but still leave financial and cascading impacts. All of these factors must be taken into consideration when assessing vulnerabilities of the chemical infrastructure.

While new and more advanced technology can enhance mitigation, preparedness, response, and communications for events impacting the chemical sector, it is not the complete solution to the potentially devastating impacts of such incidents. Effective, continuous, and up-to-date information is crucial prior to, during, and after a disaster situation. Research has shown that one of the most significant problems with warnings and dissemination of risk or disaster information is how this information is communicated to the general public. Such communication must take into account the audience's cultural background, language preference, and other socioeconomic characteristics that may significantly influence the receipt of and response to the message. The historical accident record and recent events such as Hurricanes Katrina and Rita highlight the need for effective disaster mitigation, preparedness, response, and recovery initiatives; raising community awareness; increasing disaster training for emergency response personnel and decision makers; and enhancing intra- and interorganizational communication and coordination at all levels of government and with the general public.

Appendix A

Historical Scenarios

The following historical incidents provide some perspective on the magnitude of the consequences that might result from the kinds of terrorist attacks described in the scenarios in Chapter 3. These incidents also served as a basis for the development of those four scenarios. This is not a comprehensive list of all relevant historical incidents in the chemical industry.

High-Volume Storage Scenario
Toxic or Flammable Chemicals at Fixed Sites

Stage One Historical Analogies (single event, no cascading events)

Facility: Azote de France Fertilizer Factory (owned by Atofina)
Location: Toulouse, France
Date of Event: September 21, 2001
Chemical(s) involved: Ammonium nitrate
Event: Explosion
Consequences of Event: 30 killed (7 off-site), 800 hospitalized, 2,400 injured, shock wave of 3.4 on the Richter scale, 50-foot crater resulted; 500

homes uninhabitable and 85 schools or colleges damaged; chemical releases and structural damages at other facilities.[1]

Facility: Phillips Petroleum
Location: Pasadena, Texas
Date of Event: October 23, 1989
Chemical(s) involved: Plastics manufacturing
Event: An explosion in a polyethylene reactor was caused when a seal blew out on an ethylene loop reactor, releasing ethylene-isobutane and setting off a series of fires and explosions.
Consequences of Event: 23 fatalities, 130-300 injured; extensive facility damage.[2]

Facility: Marathon Refinery
Location: Texas City, Texas
Date of Event: 1987
Chemical(s) involved: Hydrofluoric acid
Event: Construction at Marathon refinery severs a pipe on an anhydrous hydrofluoric acid storage tank, releasing gas that forms a dense hydrofluoric acid vapor cloud that migrates through the community.
Consequences of Event: Approximately 4,000 people were evacuated and more than 1,000 were treated for injuries.[3]

Facility: BP Refinery
Location: Texas City, Texas
Date of Event: March 23, 2005
Chemical(s) involved: Unknown
Event: Overfill of flammable hydrocarbons in the tower of an octane boosting unit led to an explosion.

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[1]Dechy, N., T. Bourdeaux, N. Ayrault, M-A. Kordek, and J.C. Le Coze. 2004. First lessons of the Toulouse ammonium nitrate disaster, 21st September 2001, AZF plant, France. *Journal of Hazardous Materials* 111:131-138.

[2]U.S. Fire Administration. 1989. *Phillips Petroleum Chemical Plant Explosion and Fire: Pasadena, Texas*, USFA-TR-035. Emmitsburg, MD.

[3]Health and Safety Executive. Accident Summary: Release of Hydrofluoric Acid from Marathon Petroleum Refinery, Texas, USA, 30th October 1987. Available at *http://www.hse.gov.uk/comah/sragtech/casemarathon87.htm.*

Consequences of Event: 15 people were killed and more than 100 were wounded.[4]

Facility: Union Carbide Corporation
Location: Bhopal, India
Date of Event: December 3, 1984
Chemical(s) involved: Methyl isocyanate (MIC)
Event: A relief valve lifted on a storage tank containing MIC, subsequently releasing a cloud of MIC gas onto residential areas surrounding the plant.
Consequences of Event: 3,000-7,000 people were killed immediately; 20,000 cumulative deaths; 200,000-500,000 injured; posttraumatic stress; continued medical consequences.[5]

Stage Two Historical Analogies (initial event with cascading events or major toxic release)

Facility: PEMEX LPG Terminal
Location: Mexico City
Date of Event: 1984
Chemical(s) involved: Liquefied petroleum gas (LPG)
Event: The rupture of a transfer pipe produced a gas cloud that ignited a flare stack. At a late stage, the emergency shutdown button was pressed. About 15 minutes after the initial release the first boiling liquid expanding vapor explosion occurred. For the next hour and a half, a series of boiling liquid expanding vapor explosions followed as the LPG vessels exploded violently. LPG was said to rain down and surfaces covered in the liquid were set alight. The explosions were recorded on a seismograph at the University of Mexico.
Consequences of Event: 650 dead; 6,400 injured.[6]

Facility: SS Grandcamp.
Location: Texas City, Texas
Date of Event: April 16, 1947

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[4]See the following web site for more information: *http://www.galvnews.com/story.lasso?ewcd=f21798a1b23f8be1.*

[5]Lees, Frank. 1996. Loss Prevention in the Process Industries 3:A5.1-A5.11.

[6]Details available at *http://www.hse.gov.uk/comah/sragtech/casepemex84.htm.*

Chemical(s) involved: Ammonium nitrate
Event: Cargo of ammonium nitrate on the ship *SS Grandcamp* caught fire and eventually exploded at the loading dock.
Consequences of Event: More than 560 killed and 2,000 injured (unable to apportion the number killed or injured by the immediate explosion from those killed by cascading events that reflect the second portion of the scenario); explosion heard 150 miles away. There was also an explosion of a second ship containing ammonium nitrate. Other chemical releases and structural damage occurred at the nearby Monsanto Chemical Co. and other facilities.[7]

Facility: Ashland Oil Company, Inc.
Location: Floreffe, Pennsylvania
Date of Event: January 1988
Chemical(s) involved: Oil
Event: A 4 million gallon oil storage tank owned by Ashland Oil Company, Inc., split apart and collapsed at an oil storage facility near the Monongahela River. The tank split while being filled to capacity for the first time after it had been dismantled and moved from an Ohio location and reassembled at the Floreffe facility. The split released diesel oil over the tank's containment dikes, across a parking lot on an adjacent property, and into an uncapped storm drain that emptied directly into the river.[8]
Consequences of Event: The oil spill temporarily contaminated drinking water sources for an estimated 1 million people in Pennsylvania, West Virginia, and Ohio; contaminated river ecosystems; killed wildlife; damaged private property; and adversely affected businesses in the area; more than 511,000 gallons of diesel fuel remain unrecovered and are presumed to be in the rivers.

Facility: Motiva Enterprises, LLC
Location: Delaware City, Delaware
Date of Event: July 17, 2001

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[7]See the following web site for more information: *http://www.local1259iaff.org/report.htm*.

[8]Ashland Oil Spill, U.S. Environmental Protection Agency. Available at *http://www.epa.gov/reg3hwmd/super/PA/ashlandoil/*.

Chemical(s) involved: Sulfur dioxide and sulfuric acid
Event: Welding operations on a catwalk triggered a fire that propagated into an explosion in the confined headspace of a large storage tank, causing its catastrophic collapse and release of its contents.
Consequences of Event: Collapse of a spent sulfuric acid storage tank (more than 250,000 gallons), triggered releases from nearby tanks, killed one contract worker, and caused a large fish kill. Other commonly bermed tanks were immersed in concentrated sulfuric acid for several days until they could be drained, but they did not fail.[9]

Facility: First Chemical Corporation
Location: Pascagoula, Mississippi
Date of Event: October 13, 2002
Chemical(s) involved: Mononitrotoluene
Cause of Event: A 145-foot-tall mononitrotoluene distillation tower exploded, injuring three workers; large projectiles of debris ruptured a large mononitrotoluene storage tank, damaged other plant equipment, and ignited fires on- and off-site; projectiles missed nearby storage vessels containing high volumes of ammonia, hydrogen, refined petroleum liquids and gases, and other hazardous materials.[10]
Consequences of Event: Three workers injured; fires, projectiles, and other damage to the plant and plant equipment.

High-Volume Transport Scenario

Location: Baltimore, Maryland
Date of Event: July 18, 2001
Chemical(s) involved: Hydrochloric acid, ethylhexyl phthalate, and tripropylene glycol
Event: An eastbound CSX1 freight train derailed 11 of its 60 cars while passing through the Howard Street Tunnel in Baltimore, Maryland. Four of the 11 derailed cars were tank cars containing tripropylene, hydrochloric acid, and di(2-ethylhexyl) phthalate. The derailed tank car containing tripropylene was punctured, and the escaping tripropylene ignited. The fire spread to the contents of several adjacent cars, creating heat, smoke, and

[9] *http://www.csb.gov/completed_investigations/docs/DS-MotivaIR-090602.pdf.*
[10] *http://www.csb.gov/completed_investigations/docs/FirstChemFinalReport.pdf.*

fumes that restricted access to the tunnel for several days. A 40-inch-diameter water main directly above the tunnel broke in the hours following the accident and flooded the tunnel with millions of gallons of water.
Consequence of Event: Five emergency responders sustained minor injuries while responding to the incident, but there were no deaths as a result of the event. Emergency operations in the City of Baltimore were occupied by the incident, and the north-south transportation corridor on the East Coast was disrupted for days. Total costs associated with the accident, including response and cleanup costs, were estimated at about $12 million.[11]

Location: Graniteville, South Carolina
Date of Event: January 2005
Chemical(s) involved: Chlorine
Event: Due to an improperly set switch, a 42-car train collided with a parked train. The accident led to the puncture of a tank car containing chlorine.
Consequence of Event: Nine people died as a result of exposure to chlorine; more than 250 were sent to the hospital, and 5,400 were evacuated.[12]

Location: Mississauga, Ontario
Date of Event: November 1979
Chemical(s) involved: Propane, styrene, chlorine, and caustic soda
Event: A Canadian Pacific train lost a wheel resulting in the derailment of 24 cars. Six of these cars separately contained propane, styrene, chlorine, caustic soda, and fiberglass insulation. The mixture of these chemicals caused an explosion that could be seen more than 100 km away and the mixture of chlorine and styrene, with sunlight as a catalyst, created mace.
Consequence of Event: Although there were no fatalities or serious injuries, approximately 250,000 residents were evacuated for almost a week.[13]

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[11]National Transportation Safety Board. 2001. Railroad Accident Brief. Available at *http://www.ntsb.gov/publictn/2004/RAB0408.pdf.*

[12]*http://pubs.acs.org/cen/news/83/i03/8303notw1.html.*

[13]City of Mississauga. Train Derailment. Available at *http://www.mississauga.ca/portal/cityhall/trainderailment.*

Chemical Shortage Scenario

The following flu outbreaks provide a basis for assessing the magnitude of these events.

	Date	Fatalities	Mortality Rate
Spanish flu (U.S.)	1918-1919	670,000	6.5/1,000
Asian flu (U.S.)	1957-1958	70,000	
Normal year (U.S.)		36,000 (200,000 hospitalizations)	0.07/1,000

Misuse Scenario

Location: Chicago, Illinois
Date of Event: 1982
Substance(s) involved: Cyanide, Tylenol
Event: Seven people died as a result of taking Tylenol that had been contaminated with cyanide. A wave of copycat poisonings in the following years led to additional deaths.
Consequence of Event: To restore consumer confidence, new packaging procedures were implemented by all manufacturers. The Tylenol case was never solved. As a result, the company's market value fell by $1 billion.[14]

Location: The Dalles, Oregon
Date of Event: 1984
Substance(s) involved: *Salmonella typhimurium*
Event: A series of restaurant salad bars were intentionally contaminated with *S. typhimurium* in an effort to affect the results of a local election.
Consequence of Event: Twelve percent of the town became ill and a third of the town's restaurants were closed.

Location: On the East Coast
Date of Event: Fall 2001
Substance(s) involved: Anthrax
Event: Letters laced with the bacteria *Bacillus anthracis*, commonly known as anthrax, were mailed to two U.S. Senators and a variety of media outlets.

[14] *http://www.mallenbaker.net/csr/CSRfiles/crisis02.ht*ml.

The anthrax attacks occurred over the course of several weeks beginning on September 18, 2001. The crime is suspected to be domestic and intended to frighten and raise public fear rather than kill large numbers of people.[15] There were also occurrences of copycat letters being mailed. Contaminated sites were closed for cleanup ranging from three months to more than three and a half years. Estimated costs for decontamination of these sites were approximately $242.5 million.[16]
Consequence of Event: Five people were killed including two postal workers, a nurse, a Connecticut woman, and an American Media, Inc., worker. The crime remains unsolved.

Location: Belgium
Date of Event: June 1999
Substance(s) involved: Dioxin
Event: In June 1999 the Belgian government discovered that fat laced with dioxin—a carcinogenic by-product of the manufacture of some herbicides and pesticides—was used to make feed for poultry, pork, and cattle.
Consequence of Event: An initial ban on poultry resulted when some chickens showed levels of dioxin up to 1,000 times the accepted limits. Soon there was speculation that beef and pork could also be contaminated. Subsequently, the government withdrew all beef, pork, and poultry products from supermarkets throughout Belgium. Police went on alert to make sure no poultry, pigs, or cattle were slaughtered or transported anywhere and went from shop to shop to ensure that all contaminated food had been removed from the shelves. Other countries including Greece, Britain, France, Switzerland, Romania, and the United States imposed bans on imports of Belgian animal products. Russian health authorities also confiscated 20 tons of ground turkey because of fears of dioxin contamination. This had an almost immediate impact on jobs in the meat industry in Belgium where one company had to lay off 1,000 of its 1,200 workers. This crisis did not result in any injuries, and lab test results subsequently revealed inconsequential levels of dioxin in these foods.[17]

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[15] *http://www.nti.org/f_wmd411/f1a6_5.html.*

[16] Kempter, Jeff. 2005. Update on Building Contamination. Presented to the National Academies' Board on Chemical Sciences and Technology, April 26.

[17] Associated Press. 1999. What's for dinner? In Belgium, not much.

Appendix B

Statement of Task

To assist the Department of Homeland Security (DHS) in its efforts to secure the Nation's infrastructure and economy against terrorist attack and other catastrophic loss, the NRC will examine the public health, economic, and national security importance to the United States of key chemicals and chemical processes. A systems analysis perspective will be utilized to suggest a methodology to prioritize risk, identify scenarios of concern, and determine investments intended to enhance the long-term stability of the Nation's chemical infrastructure. Within resources and information available, this review will:

—Identify classes of chemicals and chemical processes that are critical to the nation's security, economy, and health. These products and services will be examined according to key sectors, including but not limited to manufacturing, agriculture, food, water, and public health.

—Identify the major vulnerabilities and points of weakness in the supply chain for these chemicals and chemical processes that could lead to catastrophic consequences. Include vulnerabilities during transportation and any special vulnerability that could exist during national emergencies. Examine the possibility of cascading failures that could lead to catastrophic supply disruption.

—Assess the likely impact of a significant disruption in the supply of these chemicals and processes. Using a systems perspective, discuss the size (number of people or organizations affected, economic impact), the severity (temporary inconvenience vs. threat to long-term viability of sector, potential for injuries or loss of life, potential for environmental degradation), and the duration of such an impact. Include mitigative effects such as substitute chemical supplies and processes and alternative sources.

—Identify and assess the effectiveness of current efforts to protect the chemical supply and processes from attack or to prepare for response and recovery should an attack occur.

—Identify actions (procedures, policies, technology deployment) to help prevent disruption in the supply of these chemicals and processes, and actions to mitigate loss and injury should such disruption occur.

—Identify incentives and disincentives that affect decisions to take preventative and mitigating actions.

—Discuss areas of scientific, engineering, and economic research and development that might advance the nation's capability to protect against such losses and minimize their impact. Provide estimates of when these R&D efforts might significantly advance the nation's homeland security objectives.

On the basis of this assessment, the NRC will offer some priorities for protection of key national assets.

Appendix C

Committee Membership

Linda Capuano, chair, was recently named senior vice president of design and engineering at Solectron Corporation, a leading provider of electronics manufacturing and integrated supply chain services. In her role, Dr. Capuano will build and expand Solectron's ability to fulfill customers' engineering and design needs, specifically in the areas of service offerings and increasing the company's collaborative engineering capabilities worldwide. In this global function, vice presidents of design and engineering in the Americas, Asia-Pacific, and Europe will report to her directly. Dr. Capuano joins Solectron from Advanced Energy Industries, a global leader in the development and support of technologies critical to high-technology manufacturing processes, where she was an executive vice president, responsible for leading corporate marketing and global sales and services. Prior to Advanced Energy Industries, Dr. Capuano held the position of corporate vice president, Technology Strategy at Honeywell where she led worldwide engineering strategy. She came to Honeywell through its merger with Allied Signal. At Allied Signal, Dr. Capuano's positions included general manager of commercial air transport auxiliary power unit products and vice president of strategic marketing and business development. She was the vice president of operations and business development, and chief financial officer of Conductus, a telecommunications superconductive electronics business in Sunnyvale, California. Dr. Capuano has also held product management positions in magnetic memory recording at IBM. Dr. Capuano has served on numerous committees advising the federal government on its technical planning exercises, including the National Academies Committee for Review of the U.S. Climate Change Science Program Strategic Plan and the Department of Energy (DOE) Task Force on Alternative Futures for the DOE National Laboratories (the Galvin Committee). She has also worked as an independent consultant in business and technology strategy, with experience in global strategic planning and in developing roadmaps to realize those strategic plans. Dr. Capuano holds a B.S. in chemistry from the State University of New York at Stony Brook, a B.S. in chemical engineering and an M.S. in chemistry from the University of Colorado, and an M.S. in engineering management and Ph.D. in materials science from Stanford University.

Lisa M. Bendixen is an expert in hazmat risk and safety and has worked on risk assessment and management problems in numerous industries covering both fixed facilities and transportation systems. She was the project manager and primary author of the Guidelines for Chemical Transportation Risk Analysis, published by the American Institute of Chemical Engineers' (AIChE) Center for Chemical Process Safety and has served on the center's technical steering committee. She also applies her skills and experience to a range of security issues. She served on the Transportation Security Panel for the National Research Council's (NRC) report *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* and has worked on the development and review of critical infrastructure protection plans in response to Homeland Security Presidential Directive-7 (HSPD-7). She is currently a vice president with ICF Consulting and previously spent 22 years in Arthur D. Little, Inc.'s, environment and risk practice. Ms. Bendixen holds a B.S. degree in applied mathematics and an M.S. degree in operations research, both from the Massachusetts Institute of Technology.

Anthony J. Finizza is the former chief economist at ARCO, a position he held from 1982 to 1998. His responsibilities included monitoring alternative fuel vehicle developments and energy-economic studies. Prior to this position, he was regional vice president of Data Resources, Inc. (1970-1975) and vice president and economist of Northern Trust Co. (1968-1970). Dr. Finizza has contributed his expertise to various professional organizations, including the International Association for Energy Economics, of which he was president (1996). He has served on several NRC committees, including the Committee to Review the R&D Strategy for Biomass-

Derived Ethanol and Biodiesel Transportation Fuels, the Committee on the Advanced Automotive Technologies Plan, and the Committee on Energy Conservation Research. He currently is an energy consultant for various clients and is a lecturer at the University of California, Irvine. He received his Ph.D. in economics from the Graduate School of Business at the University of Chicago.

Dennis C. Hendershot, is senior process safety specialist at Chilworth Technology, Inc. Prior to joining Chilworth, Mr. Hendershot was senior technical fellow in the Process Hazard Analysis and Environmental Engineering Department of the Engineering Division at Rohm and Haas Company (where he has worked since 1970). He has a B.S. in chemical engineering from Lehigh University (1970) and a M.S. in chemical engineering from the University of Pennsylvania (1978). His research interests include the development of inherently safer and environmentally friendlier processes and products; implementation of inherently safer design principles at all stages in the life cycle of a chemical process, from initial conception through an operating manufacturing plant; identification and evaluation of chemical process hazards; risk management, including risk decision making tools; development and use of both qualitative (hazard and operability studies [HAZOP], checklists, safety health and environmental reviews) and quantitative (fault tree analysis, accident consequence modeling, human reliability analysis) hazard analysis techniques, as well as chemical accident investigation techniques; and safety engineering, particularly emergency relief system design, static electricity hazards, and dust explosion hazards

Robert L. Hirsch is currently a senior energy program advisor at SAIC. His past positions include senior energy analyst at the RAND; executive advisor to the president of Advanced Power Technologies, Inc.; vice president, Washington Office, Electric Power Research Institute; vice president and manager, Research and Technical Services Department, ARCO Oil and Gas Company; chief executive officer (CEO) of ARCO Power Technologies, a company that he founded; manager, Baytown Research and Development Division and general manager, Exploratory Research, Exxon Research and Engineering Company; assistant administrator for solar, geothermal, and advanced energy systems (presidential appointment) and director, Division of Magnetic Fusion Energy Research, U.S. Energy Research and Development Administration. He has served on numerous private and government advisory committees and on several NRC studies. He is past chairman of the NRC Board on Energy and Environmental Systems and is a national associate of the National Academies. His expertise is in energy research, development, management, and business, and he has written extensively on public policy. He received a Ph.D. in engineering and physics from the University of Illinois.

Barry M. Horowitz is professor of systems engineering at the University of Virginia. Prior to that, he was chairman and founder of Concept Five Technologies, an e-business solutions provider specializing in applying enterprise application integration (EAI) and security technologies to business-to-business (B2B) systems. He was also president and CEO of MITRE Corporation and president and CEO of Mitretek Systems. Dr. Horowitz was awarded the highest civilian award of the U.S. Air Force for his contributions to the Gulf War related to locating, tracking, and destroying SCUD missiles. He holds a B.S.E.E. from City College of New York and an M.S.E.E. and Ph.D. in electrical engineering from New York University. Dr. Horowitz is also a member of the National Academy of Engineering.

William R. Koch is the global director of process safety integrity with Air Products and Chemicals, Inc. He has more than 30 years of engineering and technical experience at Air Products and has held numerous engineering management positions including, manager of product development, advanced separations group, manager of liquid bulk engineering, manager of gas systems engineering and manager of hydrocarbon engineering. He received his B.S.Ch.E. from Lafayette College (1968) and his M.S.Ch.E. from the University of Oklahoma (1972).

His most recent promotion is to a position, newly created in response to the 9/11 incident, entitled global director, process safety integrity. In this new role, Mr. Koch is accountable for ensuring that the company's global operations and future designs are secure against acts of terrorism. He is also responsible for Air Products Global Crisis Management Program and reports regularly to the company's Environmental, Health and Safety Management Committee.

Koch was a member of the American Chemistry Council and Center for Chemical Process Safety Security Task Forces that developed a Security Vulnerability Assessment (SVA) criterion and methodology for the chemical industry. He is vice chairman of the Compressed Gas Association Security Committee and the National Petrochemical and Refiners Association Security Committee. The National Petrochemical and Refiners Association is a national trade association whose members include virtually all of the refiners and petrochemical manufacturers in the United States. Koch's education is in chemical engineering.

Howard C. Kunreuther is the Cecilia Yen Koo Professor of Decision Sciences and Public Policy at the Wharton School, University of Pennsylvania, and co-director of the Wharton Risk Management and Decision Processes Center. He has a long-standing interest in ways that society can better manage low-probability, high-consequence events as they relate to technological and natural hazards and has published extensively on the topic. Dr. Kunreuther was a member of NRC's Board on Natural Disasters and chaired the H. John Heinz III Center Panel on Risk, Vulnerability, and True Costs of Coastal Hazards. He is a recipient of the Elizur Wright Award for the publication that makes the most significant contribution to the literature of insurance; and he is a distinguished fellow of the Society for Risk Analysis and received the society's Distinguished Achievement Award in 2001. He is the author with Paul Freeman of *Managing Environmental Risk Through Insurance* (published by Kluwer Academic Publishers in 1997); coeditor (with Richard Roth, Sr.) of *Paying the Price: The Status and Role of Insurance Against Natural Disasters in the United States* (published by Joseph Henry Press in1998); and coeditor (with Steve Hoch) of *Wharton on Making Decisions* (published by John Wiley and Sons in 2001). He holds an A.B. degree in economics from Bates College and a Ph.D. degree in economics from the Massachusetts Institute of Technology.

Michael K. Lindell is professor of landscape architecture and urban planning and senior faculty fellow of the Hazard Reduction and Recovery Center at Texas A & M University. He received his Ph.D. in social psychology from the University of Colorado with a specialty in disaster research and has completed hazardous materials emergency responder training through the hazardous materials specialist level. Dr. Lindell has more than 30 years of experience in the field of emergency management, during which time he has conducted a program of research on the processes by which individuals and organizations respond to natural and technological hazards. Much of his research has examined the processes by which affected populations respond to warnings of the imminent threat of a natural or technological hazard. In addition, he has conducted organizational research examining the effects of disaster experience and the community planning process on the development of emergency preparedness. Lindell has served as adjunct faculty for the Federal Emergency Management Agency's National Emergency Training Center, Istanbul Technical University, and the Taiwanese government. He also has been an instructor in workshops sponsored by federal agencies for state and local emergency planners throughout the country and has appeared as a panelist in conferences on protective actions in hazardous materials emergencies. Dr. Lindell has been a consultant to the International Atomic Energy Agency, the U.S. Nuclear Regulatory Commission, and numerous Department of Energy National Laboratories, electric utilities, and chemical companies.

Gerald V. Poje served as a board member of the U.S. Chemical Safety and Hazard Investigation Board (CSB) from its inception in November 1997 to November 2005. He also has been the board's executive administrator responsible for personnel administration, conduct of work, and representing the CSB before Congress and the Executive Branch. Prior to joining the CSB, Poje directed international programs and public health for the National Institute of Environmental Health Sciences, focusing on issues of disease prevention, health promotion, and environmental justice. He also served on U.S. delegations to intergovernmental meetings on chemical safety and promoted the development of international information networks to enhance global understanding of chemical hazards and their risks. He received his Ph.D. from New York University and served on the faculty at Miami University of Ohio. He has been a senior scientist for the National Wildlife Federation and vice president for research at Green Seal. Poje has testified before Congress advocating improvements to public health and worker protection and safety, pollution prevention policy, clean air policy and regulations, chemical accident prevention, and Y2K and chemical safety policies.

Donald Prosnitz is the deputy director of strategic plans for homeland security at the Lawrence Livermore National Laboratory (LLNL). His responsibilities include guiding strategy for comprehensive solutions; integrating threat, vulnerability, and trade-off analyses; and advanced technologies' field-demonstrated prototypes and operational capabilities to assist federal, state, local, and private entities in defending against catastrophic terrorism. His previous positions at LLNL have included chief scientist for nonproliferation, arms control, and international security, and he has provided technical support for DOE's Chemical and Biological National Security Program. In 1999, he became the first chief science and technology advisor for the Department of Justice, a position he held until 2003.

Havidán Rodríguez is the director of the Disaster Research Center and professor in the Department of Sociology and Criminal Justice at the University of Delaware. He obtained his Ph.D. in sociology at the University of Wisconsin. He was also the director of the Center for Applied Social Research at the University of Puerto Rico-Mayagüez (UPRM) and served as director of the Minority Affairs Program for the American Sociological Association. Dr. Rodríguez has been a visiting professor at the University of Michigan's Population Fellows Program (2001-2003) and was selected as the Frey Foundation Distinguished Visiting Professor, at the University of North Carolina-Chapel Hill (spring, 2002). Currently, Dr. Rodríguez serves as a member of the Disaster Roundtables of the National Research Council. He has also served on a number of review panels for the National Science Foundation (NSF). Rodríguez has received funding from NSF, the Ford Foundation, the National Institute of Mental Health, the Federal Emergency Management Agency, the U.S. Army Corps of Engineers, and the UPRM Sea Grant Program, among others, for a number of research projects on the social science aspects of hazards and disasters and for research projects aimed at providing hands-on research training and mentoring to undergraduate and graduate students. He is currently working on two research projects focusing on population composition, geographic distribution, natural hazards, and vulnerability in the coastal regions of Puerto Rico (funded by the UPRM Sea Grant Program), and he is a lead social science researcher for the Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), funded by NSF.

Peter H. Spitz is a founder of Chemical Advisory Partners, a consultancy that assists senior management of chemical firms and financial buyers on issues relating to growth, profitability, acquisitions, and globalization. After obtaining bachelor's and master's degrees in chemical engineering from MIT, Spitz held successive management positions at Esso Engineering and at Scientific Design Company (which successfully developed a number of petrochemical processes) before founding Chem Systems, a leading international management consulting firm. He has written extensively on the industry, including two books: *Petrochemicals, the Rise of an Industry*, published by John Wiley and Sons in 1988 and, more recently, *The Chemical Industry at the Millennium: Maturity, Restructuring, and Globalization*, published by Chemical Heritage Foundation in 2003.

Appendix D

Meetings and Presentations

Meeting 1
December 13-14, 2004
Washington, D.C.

Dealing with the Media
William Kearney, Director of Media Relations
The National Academies Office of News and Public Information

S&T for Protection of the Chemical Infrastructure
John Cummings, Director of Critical Infrastructure Protection Portfolio, Plans, Programs and Budget
Science and Technology Directorate
U.S. Department of Homeland Security

Protection of the Chemical Infrastructure
Lawrence Stanton, Protective Security Division
Information Analysis and Infrastructure Protection Directorate
U.S. Department of Homeland Security

Charge to the Committee
William Rees, Program Manager of Homeland Security Advanced Research Projects Agency
Science and Technology Directorate
U.S. Department of Homeland Security

Meeting 2
January 10, 2005
Washington, D.C.

The Chemical Supply Chain
Rick Brown, Business Manager
National Petrochemical and Refiners Association

Jim Cooper, Senior Manager of Government Relations,
Synthetic Organic Chemical Manufacturers Association

John Felmy, Chief Economist and Director of Statistics Department
American Petroleum Institute

Kathleen Shaver, President
The Chlorine Institute

Kevin Swift, Senior Director for Economics
American Chemistry Council

Meeting 3
February 14-15, 2005
Washington, D.C.

Inorganic Materials
Pamela Guffain, Director, Government Relations
The Fertilizer Institute

Ford West, Senior Vice President, Government Relations
The Fertilizer Institute

Pharmaceutical Supply Chain
Sanjay Amin, Senior Director-Team Leader API—Americas Area
Pfizer, Inc.

Alister Thomson, Director of Strategy and Resource Optimization
Bristol-Myers Squibb

Pharmaceutical Inventory
Michael Verdi, Drug Shortage Manager
Center for Drug Evaluation and Research, Food and Drug Administration

Susan Gorman, Associate Director for Science
Strategic National Stockpile Program, Centers for Disease Control and Prevention

Meeting 4
March 17-18, 2005
Washington, D.C.

Hydrogen Fluoride Supply Chain
Brad Kulesza, DuPont Fluoroproducts

New Jersey Homeland Security Initiative Overview
Gary Sondemeyer, Chief of Staff
New Jersey Department of Environmental Protection

Issues of Concern to Public Interest Groups and Their Ideal Outcome for This Activity
Fred Millar, Friends of the Earth
Rick Hind, Greenpeace
Carol Andress, Environmental Defense
Meghan Purvis, U.S. Public Interest Research Group
Tom Natan, National Environmental Trust

Meeting 6
May 9-10, 2005
Washington, D.C.

Protection of the Chemical Infrastructure
Lawrence Stanton and Susan Smith, Protective Security Division
Information Analysis and Infrastructure Protection Directorate
U.S. Department of Homeland Security

Appendix E

Acronyms

ACC	American Chemistry Council
AEGL	Acute Exposure Guideline Levels
ALOHA	Area Locations of Hazardous Atmospheres
API	American Petroleum Institute
CAAA	Clean Air Act Amendments
CDC	Center for Disease Control and Prevention
CDER	Center for Drug Evaluation and Research
CSB	U.S. Chemical Safety and Hazard Investigation Board
DHS	U.S. Department of Homeland Security
DIM	Disasters Impact Model
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EHS	Extremely Hazardous Substance
EOP	Emergency Operations Plan
EPA	U.S. Environmental Protection Agency
ICS/IMS	Incident Command System/Incident Management System
IDS	Interdependent Security
IEC	International Electrotechnical Commission

LD_{50}	Lethal Dose 50
NACD	National Association of Chemical Distributors
NRC	National Research Council
NTSB	National Transportation Safety Board
OSHA	Occupational Safety and Health Administration
PHAST	Process Hazard Analysis Software Tool
RAMCAP	Risk Analysis for Critical Assets Protection
RMP	Risk Management Program
SCADA	Supervisory Control and Data Acquisition
S&T	Science and Technology
SNS	Strategic National Stockpile
SOCMA	Synthetic Organic Chemical Manufacturers Association

Appendix F

Glossary

Bioaccumulative	Substances that concentrate in living organisms as they breathe contaminated air, drink or live in contaminated water or eat contaminated food rather than being eliminated through natural processes.
Brownfield	Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.
Capability	The ability and capacity to attack a target and cause adverse effects.
Cascading event	The occurrence of one event that causes another event.
Casualties	Deaths or injuries resulting from an event.
Catastrophic incident	Any natural or manmade incident, including terrorism, which results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions. A catastrophic event could result in sustained national im-

	pacts over a prolonged period of time; almost immediately exceed private sector authorities in the impacted area; and significantly interrupt government operations and emergency services to such an extent that national security could be threatened.
Emergency preparedness practices	Practices that develop the resources needed to support emergency response.
Hazard	An inherent physical or chemical characteristic that has the potential for causing harm to people, the environment, or property.
Hazard exposure	The geographical areas that could be affected by a hazardous incident.
Hazard mitigation practices	Practices that provide passive protection to persons and property at the time an incident occurs.
Hazardous incident	An event that is perceived by some segments of society as producing unacceptable impacts or as indicating the danger that such impacts might occur in the future.
Inherently safer processes	A process can be described as "inherently safer" than other process alternatives in the context of one or more specific hazards if those hazards are eliminated or greatly reduced relative to the alternative processes, and if the process characteristics which eliminate or reduce the hazards are a permanent and inseparable element of the process. This means that safety is "built in" to the process, not added on. Hazards are eliminated, not controlled, and the means by which the hazards are eliminated are so fundamental to the design of the process that they cannot be changed or defeated without changing the process.

Intent	The desire or motivation of an adversary to attack a target and cause adverse effects.
Lethal Dose 50 (LD_{50})	The dose at which 50 percent of an exposed animal model population dies.
Links	The means (road, rail, barge, or pipeline) by which a chemical is transported from one node to another.
Multiple terrorist incident	Terrorist attacks occurring simultaneously or in a series at a single location or multiple locations.
Nodes	A facility at which a chemical is produced, stored, or consumed.
Pathways	The sequence of nodes and links by which a chemical is produced, transported, and transformed from its initial source to its ultimate consumer.
Physical vulnerability	The susceptibility of persons and structures to the impacts of a hazardous incident.
Red teaming	As used here, a group exercise to imagine all possible terrorist attack scenarios against the chemical infrastructure and their consequences.
Risk	The result of a threat with adverse effects on a vulnerable system.
Single terrorist incident	A terrorist attack at a single location.
Social amplification	The many ways in which information about risks is amplified by some social processes and reduced by others.
Threat	The *intent* and *capability* to adversely affect (cause harm or damage to) the system by adversely changing its states.

Tipping	Concept (from the tipping of a scale) that refers to many others in the supply chain simultaneously investing in security measures because one or more units in the supply chain have done so.
Vulnerability	The manifestation of the inherent states of the system (e.g., physical, technical, organizational, social, cultural) that can be exploited by an adversary to adversely affect (cause harm or damage to) that system.
Vulnerable zones	Areas around a facility in which people could, but would not necessarily, be exposed to harm by a worst-case event.