Occupational Health and Workplace Monitoring at Chemical Agent Disposal Facilities

Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program, Board on Army Science and Technology, National Research Council

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Division on Engineering and Physical Sciences
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Preface

The United States has maintained a stockpile of chemical warfare agents and munitions for more than half a century. In 1985, Public Law 99-145 mandated an expedited effort to dispose of M55 rockets containing unitary chemical warfare agents because of their potential for self-ignition. This program soon expanded to become the Army Chemical Stockpile Disposal Program (CSDP), with the mission of eliminating the entire stockpile of unitary chemical agents and munitions. The Army developed the baseline incineration system for that purpose. Since 1987, the National Research Council, through the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee), has provided technical and scientific advice and counsel to the Army's disposal program and has endorsed the baseline incineration system as an adequate technology for destroying the stockpile. In 1992, after setting several intermediate goals and dates, Congress enacted Public Law 102-484, which directed the Army to dispose of the entire stockpile by December 31, 2004, a deadline that was changed to April 29, 2007, after the United States ratified the Chemical Weapons Convention.

We wish to express our appreciation to the members of the Stockpile Committee who helped in the preparation of this report by collecting significant data and information, making site visits to existing facilities and facilities under construction, and writing the report. Charles E. Kolb took the lead for the study, working closely with David H. Archer, J. Robert Gibson, Charles F. Reinhardt, and Chadwick A. Tolman. The committee is also grateful to the Office of the Program Manager for Chemical Demilitarization and its contractors for the useful information they provided.

The committee greatly appreciates the support and assistance of National Research Council staff members Donald L. Siebenaler, Harrison T. Pannella, William E. Campbell, Daniel E.J. Talmage, Jr., and Carol R. Arenberg in the production of this report.

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Committee on Review and Evaluation of the
Army Chemical Stockpile Disposal Program

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 NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards 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:

Jonathan Borak, Yale University
William L. Budde, U.S. Environmental Protection Agency
Philip K. Hopke, Clarkson University
Steven Markowitz, Queens College
Lewis D. Pepper, Boston University School of Public Health
Sylvia S. Talmage, Oak Ridge National Laboratory

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 Mark Cullen, Yale University, appointed by the Division on Engineering and Physical Sciences, who was 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 authoring committee and the institution.

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Acronyms

ACAMS	automatic continuous air monitoring system
ACOEM	American College of Occupational and Environmental Medicine
CAMDS	Chemical Agent Munitions Disposal System
CAS	Chemical Abstracts Service
CEMS	continuous emission monitoring system
CSDP	Chemical Stockpile Disposal Program
CWC	Chemical Weapons Convention
DAAMS	depot area air monitoring system
DCD	Deseret Chemical Depot
DESH	2-diisopropyl ethyl mercaptoamine
DNA	deoxyribonucleic acid
DPE	demilitarization protective ensemble
DRE	destruction and removal efficiency
DSHW	Division of Solid and Hazardous Waste
EA-2192	S-(2-diisopropylaminoethyl) methylphosphonothioc acid
EMPA	ethyl methylphosphonic acid
EPA	Environmental Protection Agency
GA	tabun (a nerve agent)
GB	sarin (a nerve agent)
H	mustard: Levinstein mustard: mixture of 70 percent bis(2-chloroethyl)sulfide and 30 percent sulfur impurities
HD	distilled mustard: bis(2-chloroethyl)sulfide
HRA	health risk assessment
HT	vesicant mixture: 60 percent bis (2-chloroethyl)sulfide and 40 percent bis[2(2-chloroethylthio)ethyl] ether
IMPA	isopropyl methylphosphonic acid
IT-SIMS	ion-trap secondary ion mass spectometry
JACADS	Johnston Atoll Chemical Agent Disposal System
MDB	munitions demilitarization building
MPA	methylphosphonic acid
NO_x	nitrogen oxide
NRC	National Research Council
OPIDN	organophosphorous-induced delayed neuropathy
OSHA	Occupational Safety and Health Administration
PAS	pollution abatement system
PDAR	process data acquisition recording
PMCD	Program Manager for Chemical Demilitarization
PRP	personnel reliability program
QAPP	Quality Assurance Program Plan
QRA	quantitative risk assessment
SCWO	supercritical water oxidation
SOPC	substance of potential concern
T	bis[2(2-chloroethylthio)ethyl] ether
TOCDF	Tooele Chemical Agent Disposal Facility
VX	a nerve agent

Executive Summary

In keeping with a congressional mandate (Public Law 104-484) and the Chemical Weapons Convention, the United States is currently destroying its chemical weapons stockpile. The stockpile initially contained more than 31,000 tons of nerve and blister chemical agents, much of which was loaded into explosive munitions, including bombs, tactical rockets, projectiles, and mines. Under the direction of the Army's Program Manager for Chemical Demilitarization, the disposal of chemical agents and munitions began in 1990 with the completion of the Johnston Atoll Chemical Agent Disposal System (JACADS). Johnston Island, approximately 825 miles southwest of Hawaii, was the only noncontinental site of stockpiled U.S. chemical agents and munitions.

The destruction of the chemical agents and munitions stored in the continental United States commenced in 1996 with initial operation of the Tooele Chemical Agent Disposal Facility (TOCDF) at Deseret Chemical Depot near Tooele, Utah, where more than 44 percent of the continental U.S. stockpile was located. A separate chemical demilitarization research and development facility, the Chemical Agent Munitions Disposal System (CAMDS), is also in operation at Deseret Chemical Depot. Chemical munitions and/or bulk containers of chemical agents are also stored at seven other continental U.S. sites. The construction of disposal facilities at five of these sites is under way, as is the process of selecting disposal technologies for the remaining two. The nation's goal is to complete destruction of the stockpile by April 29, 2007, as called for in the Chemical Weapons Convention. As of December 2000, about 22 percent of the total stockpile had been destroyed at JACADS and TOCDF. The last of the chemical weapons stored on Johnston Island were destroyed in November 2000.

Given the significant risk associated with continued storage of chemical agents and munitions, and given the international commitment for their disposal imposed by the Chemical Weapons Convention, the destruction of the remaining stockpile should proceed expeditiously, and in a manner that protects the health and safety of the workers and the public at each site. The continued operation of TOCDF and CAMDS at Deseret Chemical Depot, and the planned opening of seven other continental U.S. disposal facilities, will require a significant increase in the number of workers. In late 2000, approximately 1,300 workers (including those at JACADS) were employed. Taking into account staff turnover, and including both operating contractor and Army oversight personnel, the cumulative number of workers at all of the chemical agent disposal facilities is anticipated to increase to 8,600.

The Army must ensure that the chemical demilitarization workforce is protected from the risks of exposure to hazardous chemicals during disposal operations and during and after facility closure. Good industrial practices developed in the chemical and nuclear energy industries and other operations that involve the processing of hazardous materials include workplace monitoring of hazardous species and a systematic occupational health program for monitoring workers' activities and health. In this report, the National Research Council Committee on Review and Evaluation of the

Army Chemical Stockpile Disposal Program examines the methods and systems used at JACADS and TOCDF, the two operational facilities, to monitor the concentrations of airborne and condensed-phase chemical agents, agent breakdown products, and other substances of concern. The committee also reviews the occupational health programs at these sites, including their industrial hygiene and occupational medicine components. Finally, it evaluates the nature, quality, and utility of records of workplace chemical monitoring and occupational health programs.

In general, the committee finds that both workplace monitoring and occupational health programs at JACADS and TOCDF have been conducted in a professional manner and that current methods of detecting airborne agents are adequate. Nevertheless, recent advances in monitoring technology could reduce false alarm rates and decrease response times. Therefore, the committee recommends that the Army continue to evaluate potential improvements. The committee also identifies weaknesses in the monitoring of EA-2192, an agent breakdown product, and in the rapid quantification of contamination by agent and agent breakdown products on surfaces and in liquid and solid materials. The Army should keep abreast of advances in analytical methods and continue its efforts to develop new techniques. The committee also recommends that the Army monitor advances in biomedical diagnostic techniques that could provide more sensitive measurements of very low level exposures to blister agents.

Finally, based on past experiences, many employees are likely to work at more than one chemical agent disposal facility. Therefore, an analysis of workplace monitoring and/or occupational health data for several sites may be necessary to assess histories of individual workers and identify systemwide trends. Cross-site data reviews and analyses could be greatly improved if contractors used standardized reporting formats, which would facilitate electronic access to data records from all sites. The committee recommends the adoption of standardized report formats and electronically accessible records for occupational health and related records. Detailed findings and recommendations are presented in Chapter 5.

1

Introduction

For more than 50 years, the United States has maintained a stockpile of chemical agents and munitions distributed among eight sites in the continental United States and on Johnston Island in the Pacific Ocean. The nation is currently engaged in a concerted effort to destroy the materials stored at these sites safely and efficiently. An estimated cumulative total of more than 8,600 operating and oversight personnel will be required to staff currently operating and future chemical agent disposal facilities, and the safety and health of these employees is a high priority. This report examines and evaluates workplace chemical monitoring and worker health monitoring practices at currently operating disposal facilities.

CHEMICAL AGENT AND MUNITIONS STOCKPILE

Two basic types of chemical agents comprise the stockpile: cholinesterase-inhibiting (nerve) agents and blister (mustard and Lewisite) agents. Both types are frequently, and erroneously, referred to as "gases" even though they are liquids at normal temperature and pressure.[1]

Nerve agents include organic phosphorus compounds designated VX, GB (sarin), and GA (tabun). These chemicals present a significant toxic hazard because of their action on the nervous systems of humans and animals through inhibition of the acetylcholinesterase enzyme. VX is more acutely toxic than GB, but the latter represents a greater initial exposure hazard because of its higher volatility (about the same as water) and the greater likelihood of its being inhaled. Cancer has not been associated with exposure to nerve agents or chemically and toxicologically similar commercial organic phosphorus insecticides (U.S. Army, 1999a). In general, chronic health effects in humans have not been associated with either long-term, low-level exposures or short-term, high-level exposures to nerve agents (CDC, 1988).

Some concerns have been expressed about the induction of organophosphorous-induced delayed neuropathy (OPIDN) by the nerve agents, as well as other possible delayed or persistent effects, such as cardiac dysfunction, psychological effects, and electroencephalographic abnormalities. In a comprehensive study of these effects, Munro et al. (1994) came to the following conclusions: (1) no exposures to nerve agents have resulted in OPIDN; (2) these agents are not likely to be carcinogenic; (3) these nerve agents are not teratogenic; and (4) they do not have deleterious

[1]The *stockpile* (the subject of the Army's Chemical Stockpile Disposal Program) consists of (1) bulk containers of nerve and blister agents and (2) munitions, including rockets, mines, bombs, projectiles, and spray tanks, loaded with nerve or blister agents. Buried chemical warfare materiel, recovered chemical warfare materiel, binary weapons (in which two nonlethal components are mixed after firing to yield a lethal nerve agent), former production facilities, and miscellaneous chemical warfare materiel are not included in the stockpile. The disposition of these five classes of materials is the subject of a separate Non-Stockpile Chemical Materiel Program. Information on the Army's overall chemical material disposal programs is available online at <http:www-pmcd.apgea.army.mil/text/w_body.html>.

effects on reproductive function in doses that are not maternally toxic. Moderate or higher exposures to GB have been associated in some individuals with transient difficulties in concentration, anxiety, and depression for days or weeks after exposure. Occupational exposures have been associated with subtle changes on electroencephalograms of undefined significance. Animal studies suggest that cardiac toxicity may be associated with severe acute nerve-agent exposure, but no conclusive evidence of these effects has been observed in humans (Munro et al., 1994). Therefore, no adverse acute or chronic effects are expected if exposure guidelines are followed.

Sulfur mustards (designated H [mustard], HD [distilled mustard], and HT [HD and T mixture]) do not present acute lethal hazards. Their principal effect is severe blistering of the skin and mucous membranes. Epidemiological evidence indicates a causal relationship between exposure to mustard agent at high concentrations and the development of chronic nonreversible respiratory disorders, such as chronic bronchitis and asthma, and ocular diseases, such as delayed recurrent keratitis and prolonged, intractable conjunctivitis (IOM, 1993). Sulfur mustard has been classified as a known human carcinogen based on evidence of increased mortality from respiratory tract cancer in humans. The increase was greater in individuals with long-term occupational exposure than in those with sporadic exposure (IOM, 1993; NTP, 2000). Estimates of cancers induced as a result of accidental exposures to agent apply only to mustard agents.

Once chemical agents are fully dispersed, they do not tend to persist in the environment because of their high chemical reactivity, particularly with water (hydrolysis). However, in extremely dry desert climates, they can persist for considerable periods of time (U.S. Army, 1988). The major environmental degradation products of nerve and mustard agents have recently been assessed and their persistence and toxicity evaluated. A potential hydrolysis product of VX (S-(2-diisopropylaminoethyl) methylphosphonothioic acid [EA-2192]) is a degradation product expected to display a high level of mammalian toxicity. Some mustard partial hydrolysis products are also toxic (Munro et al., 1999).

Chemical agents in the U.S. stockpile are stored in a variety of containers and munitions, including bulk (ton) containers, rockets, projectiles, mines, bombs, cartridges, and spray tanks. Figure 1-1 summarizes the stockpile configuration for the eight continental U.S.

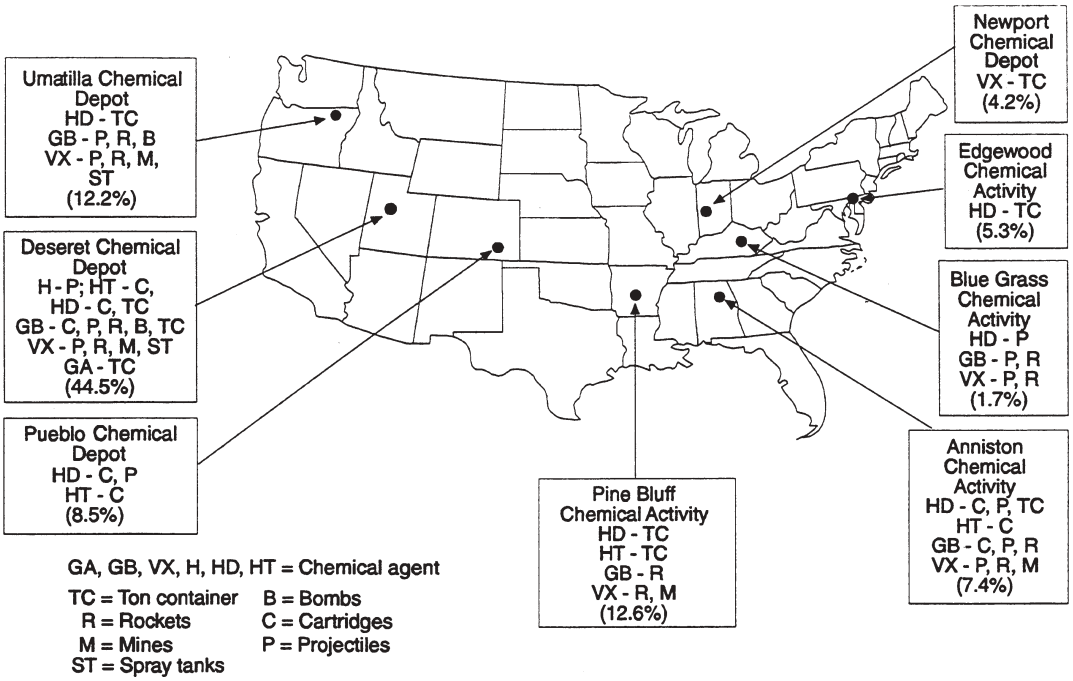

FIGURE 1-1 Location and size (percentage of original stockpile) of eight continental U.S. storage sites.
Sources: NRC, 1997a; OTA, 1992.

sites by agent and munition or containment system prior to the start of agent destruction operations at the Tooele Chemical Agent Disposal Facility (TOCDF) (NRC, 1997a).

CALL FOR DISPOSAL

Chemical Stockpile Disposal Program

Because of the aging of stockpiled chemical weapons, the continuing costs of storage, and the potential for accidental release, the United States has strong incentives to dispose of these weapons. In 1985, Congress enacted Public Law 99-145 to initiate the process of eliminating the U.S. chemical weapons stockpile with an expedited program to dispose of M55 rockets. These munitions are especially worrisome because they contain agent, explosives, and propellants in an integrated configuration and because the stabilizer components of the propellants degrade with age—thus increasing the potential for autoignition. In 1992, Congress enacted Public Law 104-484, which directed the Army to dispose of the entire unitary[2] chemical agent and munitions stockpile by December 31, 2004. Congress also directed that the Chemical Stockpile Disposal Program (CSDP) be implemented in a manner that ensures maximum protection of workers, the public, and the environment. In 1997, the Chemical Weapons Convention (CWC) (see below) was ratified by Congress, setting a disposal deadline of April 29, 2007.

Chemical Weapons Convention

The CSDP has evolved in parallel with worldwide efforts to control chemical agent precursors and eliminate chemical agents and munitions. Over the course of several decades, a broad, complex agreement known as the CWC was negotiated. Since 1993, the CWC has been signed by 174 countries and ratified by more than 140. The convention went into effect on April 29, 1997, six months after 65 countries had ratified it. Since then, both the United States, which was actively involved in negotiating the CWC agreement, and Russia, the world's largest holder of chemical agents and munitions, have also ratified it.

The CWC prohibits the development, production, acquisition, stockpiling, retention, transfer, or use of chemical weapons. Article IV requires that signatories destroy chemical weapons and any special facilities for their manufacture within 10 years (by April 29, 2007). Destruction of chemical weapons is defined as "a process by which chemicals are converted in an essentially irreversible way to a form unsuitable for production of chemical weapons, and which, in an irreversible manner, renders munitions and other devices unusable as such" (Smithson, 1993). The method of destruction is determined by each country, but the manner of destruction must ensure public safety and protection of the environment.

DISPOSAL TECHNOLOGY

In the early 1980s, the Army investigated a number of strategies for the disposal of chemical weapons. Among these were chemical destruction ("neutralization"), ocean disposal (now banned by federal law), stockpile consolidation with subsequent destruction, and disassembly followed by incineration of the various components. The Army selected incineration as the preferred technology for stockpile disposal. The National Research Council (NRC) Committee on Demilitarizing Chemical Munitions and Agents was formed in August 1983 to review the status of the stockpile and to assess available disposal technologies. In that committee's final report in 1984, incineration was endorsed as an adequate technology for the safe disposal of chemical warfare agents and munitions (NRC, 1984).

Pursuant to the enactment of Public Law 99-145, the Army began to develop the components of a baseline incineration system at its research and development facility, the Chemical Agent Munitions Disposal System (CAMDS), located at Deseret Chemical Depot (DCD), formerly a part of Tooele Army Depot, Utah.

In 1987, the NRC Committee on the Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee) was formed to advise the CSDP. Construction and systemization (operational testing) of the first fully integrated baseline incineration system, the Johnston Atoll Chemical Agent Disposal System (JACADS), was completed in June 1990

[2]The term *unitary* refers to a single chemical loaded in munitions or stored as a lethal material. *Binary* munitions have two relatively safe chemicals loaded into separate compartments; the chemicals are mixed to form a lethal agent only after the munition is fired or released. The components of binary munitions are stockpiled separately, in separate states, and are not included in the present Chemical Stockpile Disposal Program. However, under the Chemical Weapons Convention of 1997, they are included in the munitions that will be destroyed.

on Johnston Island, located in the Pacific Ocean approximately 825 miles southwest of Hawaii. The JACADS facility, which recently completed its disposal mission and will soon start closure procedures, has had a twofold mission:

- to serve as a demonstration facility for the baseline incineration system
- to destroy the chemical agents and munitions stored on Johnston Island (completed in November 2000)

The successful demonstration of the baseline system at JACADS led to a second-generation incineration system now operating at the TOCDF in Tooele, Utah, that incorporated improvements based on JACADS operating experience, advances in the baseline technology, and recommendations by the Stockpile Committee. The design of these incineration systems (JACADS and TOCDF) is also based on the idea that the performance and safety of disposal operations would be greatly enhanced if stockpile feed materials were separated into distinct streams of agent, energetic materials, metal parts, and dunnage (packing, and associated waste material) prior to incineration. A schematic drawing of the TOCDF system is shown in Figure 1-2 (NRC, 1999a). Systemization at the TOCDF began in August 1993, and agent operations began on August 22, 1996. Prior to the start of agent operations, a quantitative risk assessment (QRA) and a health risk assessment (HRA) were conducted (U.S. Army, 1996a; Utah DSHW, 1996).[3]

In the TOCDF system, feed materials are separated inside a building with areas capable of withstanding explosions. The pressure in these and other areas where agent may be present is controlled to be lower than the ambient atmospheric pressure to prevent leakage from the building to the outside atmosphere. Two methods are used to remove agents from munitions and containers via remote control. Most containers are simply mechanically punched and drained. Projectiles, however, are not punched; following separation from associated dunnage, they are moved to a munitions processing area where they are mechanically disassembled and drained, yielding three material streams: agent, energetics, and metal parts, each of which is processed in a different incinerator or electrically heated furnace. Although energetics and metal parts may be contaminated by residual agent, the vast majority of agent (95 percent or more) is usually recovered during the draining procedure.[4] A detailed description of the TOCDF system and an analysis of its first three years of operation can be found in the recent NRC report, *Tooele Chemical Agent Disposal Facility: Update on National Research Council Recommendations* (NRC, 1999a).

The same technology operating at TOCDF, with minor modifications, is now being implemented at three other storage sites (Anniston, Alabama; Umatilla, Oregon; and Pine Bluff, Arkansas). Both mustard and nerve agents are stored at these sites along with significant numbers of munitions filled with agent.

The stockpile (HD) at Aberdeen, Maryland, and the stockpile (VX) at Newport, Indiana, contain only the bulk chemical agents indicated in parentheses. At these facilities, the Army has decided to use chemical neutralization (hydrolysis) as the primary agent destruction method, followed by biological treatment at Aberdeen and supercritical water oxidation (SCWO) at Newport. A description of the process technology designs for these facilities, and the Stockpile Committee's evaluation of these designs, can be found in *Integrated Design of Alternative Technologies for Bulk-Only Chemical Agent Disposal Facilities* (NRC, 2000a).

Disposal technologies have not yet been selected for stockpile storage sites at Pueblo, Colorado, and Blue Grass, Kentucky. In addition to modified incineration technology, several alternative disposal technologies are being considered for implementation at these sites. The alternatives are discussed in two recent NRC reports (NRC, 1999b, 2000b).

CHEMICAL DEMILITARIZATION WORKFORCE

A substantial workforce is or will be involved in the operation of JACADS, CAMDS, and the eight continental U.S. chemical disposal facilities. The Army has estimated that total employment, counting both operating contractor and Army oversight personnel at the

[3]The TOCDF QRA estimates the risk to the public and workers from accidental releases of chemical agent associated with all activities during storage at DCD and throughout the disposal process at the TOCDF. The HRA, which was conducted by the Utah Division of Solid and Hazardous Waste (Department of Environmental Quality), is a screening analysis to estimate possible off-site human health risks associated with exposure to airborne emissions from the TOCDF under normal and upset conditions. The HRA also estimates risks to wildlife and the environment.

[4]At JACADS, recovery of HD from projectiles was difficult because of agent solidification, which necessitated modifications in disposal procedures.

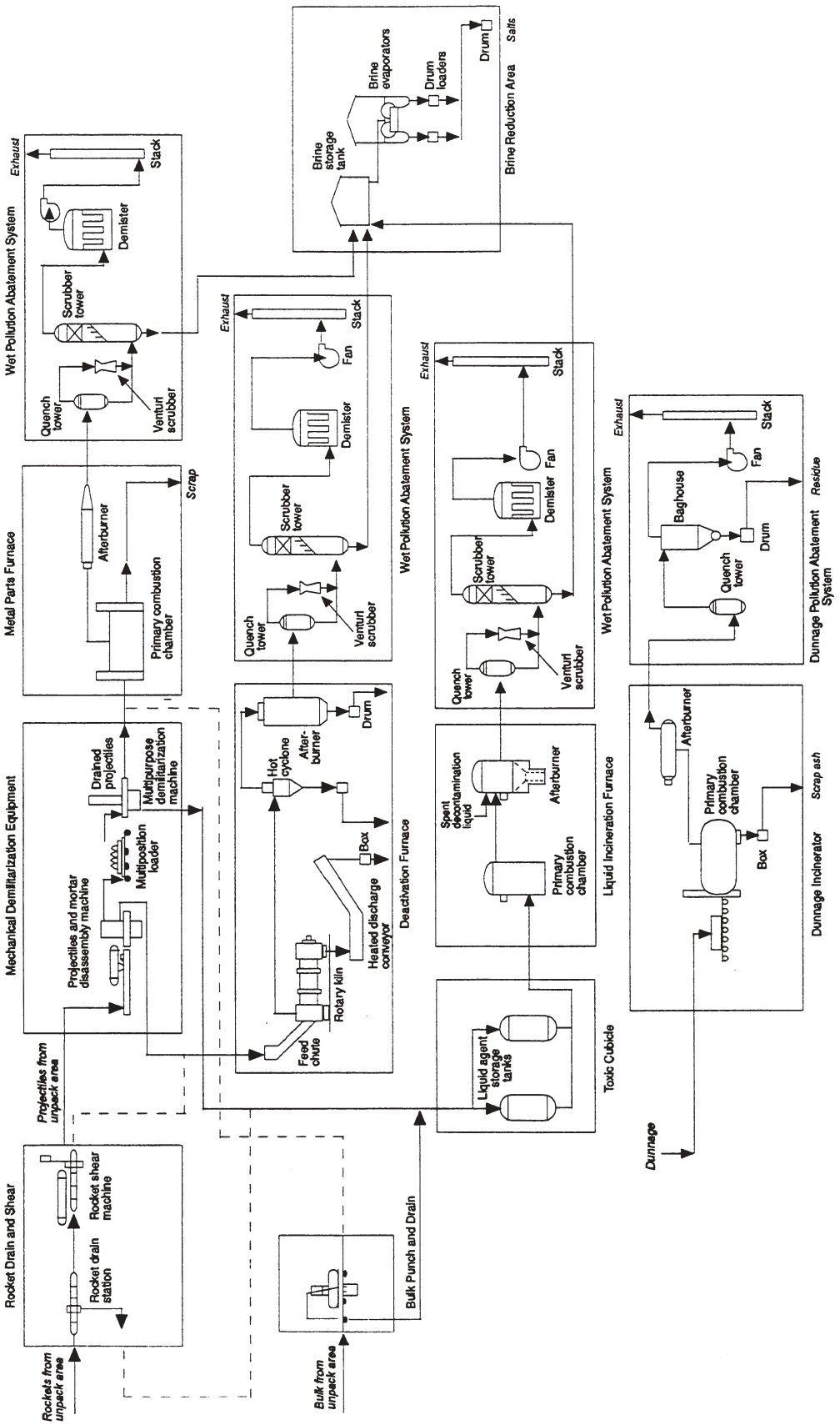

FIGURE 1-2 Schematic drawing of the TOCDF incineration system. Source: Adapted from NRC, 1994a, 1994b, 1994c, 1999a; U.S. Army, 1988.

continental facilities, will total more than 8,600 over the life of the disposal program. The projected employment totals estimated by the Program Manager for Chemical Demilitarization for each facility are shown in Table 1-1. However, based on operating experience at CAMDS, JACADS, and TOCDF, the total number of individuals will be smaller than indicated because some experienced operating and management personnel will move from established sites to newer ones as systemization begins. The relative distribution of contractor job categories will vary somewhat from site to site but will probably be similar to the distribution at TOCDF, which is currently about 40 percent operations personnel, 36 percent support service personnel, 12 percent office/clerical personnel, and 12 percent management/supervisory personnel.

Even allowing for employees who work at multiple disposal sites over the duration of the CSDP, Table 1-1 shows that a substantial number of people will be involved in the destruction of the stockpile. The focus of this report is on workplace chemical monitoring and worker activity and health monitoring practices at CAMDS, JACADS, TOCDF, and, by extension, at the other seven disposal facilities planned or under construction. The preparation, maintenance, and accessibility of records are also evaluated. Findings on current practices and recommendations for extending and/or improving them are then presented.

ROLE OF THE STOCKPILE COMMITTEE

Concurrent with the start of construction of JACADS in 1987, the Army requested that the NRC review and evaluate the CSDP and provide advice and counsel. The NRC established the standing Stockpile Committee for that purpose, beginning with a study of operational verification testing at JACADS, which was completed in March 1993. Several reports issued by the committee (e.g., *Recommendations for the Disposal of Chemical Agents and Munitions* [NRC, 1994a] and *Review of Systemization of the Tooele Chemical Agent Disposal Facility* [NRC, 1996]) concluded that the baseline incineration system was an adequate and safe method of disposing of the stockpile (see Appendix A for a complete list of Stockpile Committee reports).

Since its inception in 1987, the Stockpile Committee has exercised an advisory and oversight role for the Army's CSDP. Over the years, the Stockpile Committee has adjusted the composition of its membership to maintain a balance of disciplines necessary to meet the tasks at hand. Current members have expertise in analytical chemistry; biochemical engineering; chemical engineering; chemical industry management; chemical technology and manufacturing; civil engineering; combustion technology; engineering design and management; environmental engineering; environmental health policy; environmental restoration; facility clo-

TABLE 1-1 Projected Employment Totals for Chemical Agent Disposal Facilities

Site	Staff	Duration of Operation (years)	Estimated Turnover Rate (percent/year)	Total Operating Employees	Total Including Army Field Offices
CAMDS	275	25	10.0	963	963
JACADS	504	10	23.4[a]	1,801[b]	1,847
TOCDF	700	7.2	10.0	1,204	1,226
ANCDF	571	3.8	10.0	788	807
UMCDF	683	3.3	10.0	908	927
PBCDF	547	3.3	10.0	728	744
PUCDF	571	2.4	10.0	708	723
BGCDF	571	1.8	10.0	674	688
ABCDF	335	1.7	10.0	386	402
NECDF	274	1.3	10.0	310	322
TOTAL				8,470	8,649

[a]Entry for JACADS is based on operating experience.
[b]Includes additional adjustments based on operating history.
Source: Adapted from U.S. Army 2000a, 2000b.

sure; hazardous waste management; health risk assessment; incineration; industrial hygiene; materials science; mechanical engineering; monitoring and instrumentation; occupational medicine; organic chemistry; physical chemistry; risk assessment, management, and communication; safety; toxicology; urban studies; and waste treatment and minimization.

STATEMENT OF TASK AND CONTENT OF REPORT

In June 1999, the Army requested that the Stockpile Committee examine issues related to workplace chemical monitoring and worker health monitoring at the currently operating chemical disposal facilities. The committee was also asked to evaluate the adequacy of current practices for disposal facilities in the planning or construction phases. The statement of task for this study is reproduced below.

> Conduct a review of the chemical monitoring analytical methods and protocols being utilized for workplace monitoring at chemical agent disposal facilities within the Chemical Stockpile Disposal Program (CSDP).
>
> Conduct a review of chemical agent disposal facility operations and records management for the ambient air monitoring for agent, and for exhaust stack and other waste stream emissions of agent and other substances of potential concern (SOPCs) that are characteristic of these facilities. Use Occupational Safety and Health Administration, and Environmental Protection Agency criteria for initial identification and evaluation of SOPCs.
>
> Review medical monitoring and surveillance programs being used within the CSDP.
>
> Review CSDP protocols for compilation and management of medical records of facility personnel.
>
> Receive input, as appropriate, through documents and briefings from other organizations in the private and public sectors, about approaches and lessons learned from chemical monitoring of similarly complex facilities.
>
> Develop findings and recommendations.

Chapter 2 focuses on (1) ambient air monitoring for the presence of chemical agents in and around chemical agent disposal facilities and (2) the monitoring of agent and agent breakdown products in liquid media and on solid surfaces. Current monitoring practices and their systematic deployment at disposal facilities are also discussed. Chapter 3 examines worker monitoring in the context of occupational and environmental medicine as practiced at operating chemical agent disposal facilities. The components necessary for a comprehensive occupational and environmental health program are presented, and current practices at the operating sites are compared with the recommended model. In Chapter 4, current chemical monitoring, worker activity, industrial hygiene, and health record-keeping practices at operating disposal facilities are reviewed and evaluated. The continuity of records for workers employed at more than one site is examined. In Chapter 5, findings and recommendations based on the committee's evaluation are presented.

2

Workplace Chemical Monitoring

MONITORING CONSIDERATIONS

Chemical monitoring involves repeated analyses for chemicals that have the potential to affect the health and well-being of workers, the public, or the environment. Substances of potential concern (SOPCs) at chemical agent disposal facilities include chemical agents, agent breakdown products, other munitions-related chemicals and their decomposition products, and other substances created or released during agent processing or normal industrial repair or maintenance activities. Proper monitoring and awareness of chemical hazards are essential during all phases of operation—construction, startup and testing, agent and munitions destruction, and plant closure—and possibly even after the Army has relinquished control of the facilities.

Monitoring is generally required both for disposal processes and for maintenance activities when workers can potentially be exposed, as well as for emissions and wastes transported off site. SOPCs may be agents or nonagents; they may be found in the plant, in outdoor air, in liquid process or effluent streams, on surfaces in the plant, or in solid waste materials. Table 2-1 shows a number of examples of media that may require monitoring.

Although the nine U.S. stockpile storage/disposal sites have some common monitoring needs, each site also requires site-specific monitoring because of the differences in the types of chemical agents and munitions stored at each site and the technologies chosen for their destruction. All nine sites require monitoring of air and process waste streams for the agents being processed and related agent breakdown products of concern. All sites will also produce agent hydrolysis products because of the common practice of using decontamination solution (aqueous sodium hydroxide or sodium hypochlorite) to decontaminate equipment or to clean up after agent spills. Each site will also produce many other secondary wastes, including contaminated carbon and demilitarization protective ensemble (DPE) suits, tools, machinery, buildings (including concrete walls and floors), sumps, and soils. Secondary wastes will be similar at all sites and must be tested and ana-

TABLE 2-1 Media That May Require Chemical Monitoring

Media Phase	Agent or Agent Breakdown Products	Nonagents
Air	Plant air	Plant air
	Outdoor air	Outdoor air
	Stack exhaust[a]	Stack exhaust[a]
Liquid	Hydrolysate[b]	SCWO effluent[c]
	Decontamination solution	Fuels
	Brine	Caustic solution
Solid	Activated carbon	Ash[a]
	DPE[d] suits	Soil
	Soil	Concrete
	Concrete	
	Equipment and tools	

[a]For sites with baseline incineration system.
[b]For Aberdeen and Newport.
[c]For Newport only.
[d]Demilitarization protective ensemble.

lyzed to minimize worker exposure, ensure proper treatment and disposal, and meet cleanup criteria for closure. Finally, as is typical at any industrial facility, operations at each disposal site will entail a variety of maintenance and repair activities capable of generating contamination by various SOPCs. These include cleaning and degreasing with volatile solvent emissions and welding or machine operations with organic and metal emissions. Emissions from these routine industrial operations may have to be monitored on an episodic basis to validate industrial hygiene practices for controlling and minimizing worker exposures.

The sites at Aberdeen, Maryland, and Newport, Indiana, have only one agent each (HD at Aberdeen and VX at Newport) stored in bulk containers. These sites will use hot aqueous hydrolysis (hot aqueous caustic hydrolysis in the case of VX) as the first step in agent destruction. Batch analyses of liquid hydrolysates will be necessary at both sites to ensure that the defined degree of agent destruction (99.9999 percent) is met prior to secondary treatment.

Five of the stockpile sites that store (or have stored) chemical agents configured in a variety of weapons (e.g., rockets, bombs, artillery shells, mortar rounds, and mines) have used, currently use, or will use incineration as the means of disposal. Requirements for these disposal facilities include techniques for monitoring products of incomplete combustion, acid gases, and heavy metals that may elude exhaust pollution abatement systems and be emitted with exhaust gases through the common stacks.

The emphasis at the two operating baseline sites has (properly) been on gas-phase monitoring for agents because of their toxicity and the potential of airborne transport and inhalation. However, with the imminent start-up of sites using alternative liquid processing technologies and the upcoming plant closures (beginning with the closure of JACADS in 2001), monitoring for agents in liquid and solid media will become much more important.

MONITORING FOR AIRBORNE AGENT

Description

Monitoring for airborne chemical agent is a major activity at each chemical agent disposal facility. Two systems are currently being used: (1) the automatic continuous air monitoring system (ACAMS), an active system designed to provide a "near-real-time" alarm (currently ~3 to 8 minutes) if agent vapors are present; and (2) the depot area air monitoring system (DAAMS), a passive sampling system that draws air through adsorption tubes that are collected periodically for desorption and analysis in on-site laboratories. Short descriptions of these systems are provided below. More extensive descriptions can be found in the committee's report, *Review of Monitoring Activities Within the Army Chemical Stockpile Disposal Program* (NRC, 1994b), and the Army's *Monitoring Concept Plan* (U.S. Army, 1997a).

ACAMS monitors are composed of an automated air sampling system that supplies gaseous samples to a gas chromatograph that separates agent or agent-derived compounds and detects characteristic phosphorus or sulfur chemiluminescence with flame photometric detectors. ACAMS monitors can also be deployed with higher alarm levels in areas subject to operational contamination to monitor contamination levels, as well as to monitor progress during decontamination operations. ACAMS monitors are also deployed at several points in the pollution abatement system (PAS) and in the common stack for exhaust gas emissions from baseline system incinerators. Some ACAMS monitors are arranged in tandem to cut analysis cycle times in half. Alarms triggered by ACAMS monitors on the common stack automatically shut off the feed to the liquid agent incinerator to minimize potential emission of agents into the atmosphere.

DAAMS monitors contain adsorption tubes that collect chemicals from ambient air, usually over a period of several hours. These monitors are deployed in conjunction with most ACAMS monitors to provide a capability for confirming or negating an ACAMS alarm. This is important because ACAMS monitors operating at their lowest detection levels have a significant frequency of false positive alarms (NRC, 1994b, 1999a). DAAMS monitors are also deployed as perimeter monitors at disposal facility fence lines to detect any ground-level transport of agent outside the facility. Even in the absence of ACAMS alarms, DAAMS adsorption tubes are periodically collected and taken to the facility's laboratory for desorption and quantitative analysis on a research-grade gas chromatograph with flame photometric detection. A gas chromatograph with mass spectrometric detection is also available in each laboratory to help identify compounds that lead to false positive ACAMS alarms or otherwise interfere with the quantification of agents or agent derivatives.

Systematic quality control procedures are followed to ensure the reliable operation of ACAMS and DAAMS monitors. Each ACAMS monitor is routinely challenged with dilute agent solutions to confirm that appropriate alarm levels are being maintained. DAAMS tubes spiked with known agent levels are also added to field samples undergoing analysis on a random schedule to confirm that the monitoring system can detect and quantify adsorbed agent. Electronic records of ACAMS monitor alarms and challenges and the results of analyses of DAAMS tubes are created on a daily basis and eventually archived (U.S. Army, 1997a).

Exposure Limits and Process Control Levels

The alarm levels for deployed ACAMS monitors at various facility sites are typically set at 20 percent of a specific airborne exposure limit or process control level. Thus, the absence of an ACAMS monitor alarm may be assumed to indicate that no agent concentrations of more than 20 percent of the airborne exposure limit have persisted for longer than the cycle period (~3 to 8 minutes). The Army has set exposure limits and process controls at the levels mandated (in permits) for current disposal facility operations (U.S. Army, 1997a). These are reprinted in Table 2-2. The

TABLE 2-2 Airborne and Related Exposure Limits and Process Control Levels

		Exposure Limit for Each Chemical Agent (mg/m^3)		
Purpose	Applicable Level	GB	VX	HD[a]
Nonagent worker[b] and general population level	GPL	3×10^{-6}	3×10^{-6}	(1×10^{-4})[c]
Unmasked agent worker [b,d]	TWA[e,f]	1×10^{-4}	1×10^{-5}	3×10^{-3}
	Ceiling value[g]	1×10^{-4}	1×10^{-5}	3×10^{-3}
Source emission limit, process control levels	ASC	3×10^{-4}	3×10^{-4}	3×10^{-2}
	GLD	NA	NA	0.2
	ECL[h]	0.01	NA	NA
	IDLH	0.2	0.02	NA
	MPL	100	NA	100

[a]The presence of HT is determined by monitoring for the HD component.
[b]No individual is intentionally exposed to direct skin or eye contact with any amount of neat agent or to solid materials contaminated with agent.
[c]This level of detection (using a 12-hour sampling time) should be demonstrated and used at all sites where mustard is transported and destroyed.
[d]Devices for sampling and analyzing workplace air measure and alarm within 10 minutes when chemical agents are present in concentrations of one TWA or higher.
[e]The TWA is also referred to as the worker population limit (WPL).
[f]TWA DAAMS monitoring may be performed using a 12-hour method.
[g]The ceiling value is the maximum concentration an individual may be exposed to at any time for any duration. Practically, it is the average value over the maximum time required to detect and quantify the specified concentration (U.S. Army, 1990, 1991).
[h]ECL monitoring levels can vary depending on the monitoring application. The laboratory identifies each ECL monitoring level application in the site-specific agent monitoring plan.

ASC = allowable stack concentration
ECL = engineering control level
GLD = gross level detector
GPL = general population limit (24-hr day, 7-day week)
IDLH = immediately dangerous to life and health (30 min)
MPL = maximum permissible limit (with workers in DPE suits)
NA = not applicable
TWA = time-weighted average (8-hr day, 40-hr week)

Source: Adapted from U.S. Army, 1997a, 1997b.

general population limit values for VX and HD may be revised downward as a result of a review of agent standards now being done by the Army (Ruetter et al., 2000).

Assessment

ACAMS monitors, the principal agent quantification instruments throughout any disposal facility, alarm when a preset level of agent (usually 20 percent of the relevant control level for that location) has been exceeded. Signals much larger than the preset response level may saturate the signal processing algorithm, and because the duty cycle of an ACAMS monitor is less than 100 percent (i.e., samples are collected only during part of the duty cycle), confirmation that agent actually caused the signal depends on the analysis of DAAMS tubes at the same location. This analysis can give only the average agent concentration over the DAAMS tube's total exposure period, although it is reasonable to assume that most agent accumulation occurred during the period when the associated ACAMS monitor was in an alarm mode. A DAAMS tube without associated ACAMS monitoring can only indicate the average agent level between the time of deployment and the time of collection for analysis.

One potential weakness of the current airborne agent monitoring program is that ACAMS monitors are typically set to detect only the single agent currently being processed. Because individual ACAMS monitors can detect only one agent at a time, multiagent monitoring requires different ACAMS monitors for each agent. Moreover, only the agent currently being processed is usually addressed during routine DAAMS tube analysis. Thus, an accidental release of a chemical agent not being currently processed might go undetected. For instance, leaks from a mislabeled munition or a projectile filled with an unexpected or mislabeled agent in nominally agent-free areas would be missed, and contamination of the downstream processing area by the unexpected agent could go undetected. This issue was raised in the committee's 1994 monitoring report (NRC, 1994c), but the Army has judged the probability of "mislabeling" to be low enough that routine deployment of ACAMS monitors for multiagent detection is currently restricted to the plant-air carbon filtration system. Recent briefings on JACADS closure planning have indicated that multiagent monitoring will be implemented during closure operations (U.S. Army, 1999c).

Another weakness of the airborne monitoring system is the lack of real-time (< 10 seconds) agent detection. The committee has recommended that the Army develop a real-time system that uses a measurement technology independent of the gas chromatography with flame photometric detector methods used by the ACAMS and DAAMS systems (NRC, 1994b). To date, the Army's attempts to develop and demonstrate such a system have not been successful (NRC, 1999a). New interest in chemical agent detection as a key component of antiterrorism activities has spurred government and commercial activities focused on developing better airborne agent sensors (IOM, 1999). The committee has previously urged the Army to continue to monitor technological advances and to consider implementing any that are appropriate for chemical agent disposal facilities (NRC, 1999a).

The recurrent problem with the airborne monitoring system is false positives—which occur when an ACAMS alarm goes off but the presence of agent cannot be confirmed by later DAAMS tube analysis. The resulting tendency to discount alarms and to proceed as if agent were not present was graphically illustrated by an incident involving a minor release of GB at TOCDF in May 2000 (CDC, 2000).

MONITORING AGENT IN LIQUIDS AND SOLIDS

The primary processing requirement for monitoring agent in liquid media is to analyze the hydrolysates produced at Aberdeen and Newport to ensure that the mustard or VX has been thoroughly destroyed before proceeding to the secondary treatment step—biodegradation at Aberdeen and SCWO at Newport. It will also be necessary to ensure that no significant amount of agent is present in any process stream that is ready for discharge.

Because of the relatively low solubility of VX and several of its hydrolysis products in water and the salting-out effect of the high ion concentrations involved in caustic hydrolysis, there will be two liquid phases present during and after VX hydrolysis. Because the hydrolysate must be certified to be free of agent (defined as a destruction and removal efficiency [DRE] of 99.9999 percent) before it goes to the high-temperature, high-pressure SCWO reactor, both phases will have to be included in the analysis. VX, being lipophilic, is likely to partition selectively into the less dense oily phase, which constitutes about 5 percent of the hydrolysis mixture.

Agent hydrolysis by aqueous caustic solution is also used at baseline incineration system sites where decontamination solution is used to clean contaminated tools, equipment, and structural surfaces. At these sites, spent decontamination solution is processed through the liquid agent incinerator afterburner (secondary chamber) to destroy any residual agent or toxic hydrolysis products. This option will not be available at Aberdeen or Newport, where decontamination solution may be processed in the primary hydrolysis treatment step. No agent is expected to remain in decontamination solution after several days at room temperature. However, any liquids or solids shipped to off-site disposal facilities should be analyzed before shipment if there is any possibility of agent contamination. This is also true of the brine solution (primarily sodium chloride, fluoride, sulfate, and phosphate salts) left after the scrubbing of acid gases formed by combustion in incinerators.

Solids that are known to be or suspected of being contaminated with agent include activated carbon used in the air filtration system or gas masks, DPE suits, concrete in the munitions demilitarization building (MDB) or storage igloos, and agent-exposed soil, equipment, and tools. The usual methods of analysis include (1) holding the solid(s) in an enclosed space, such as a drum, at 70°F and analyzing the headspace vapor or (2) taking wipe samples from a solid surface and analyzing them by solvent extraction, followed by gas chromatography (U.S. Army, 1997a). The Army has also developed a scheme for classifying the degree of cleanliness of solid materials based on this headspace analysis method, designated 1X, 3X, and 5X.[1] Normally solids (e.g., shell casings) are not shipped off site unless they are at the 5X level (U.S. Army, 1997a). Although this level of decontamination may be satisfactory for steel or polymer materials, it may not be satisfactory for activated carbon, which has a high adsorptive capacity and could therefore give a very low agent vapor pressure even if a substantial loading of agent were present. If the temperature were raised, this agent could be released, posing a danger to anyone not properly prepared or equipped.

Agent in soil or concrete is not a problem during ordinary operations because gas-phase monitoring of agent suffices in areas where agent spills may occur. However, it is a potential problem during cleanup and closure operations when these materials must be certified as agent free.

MONITORING NONAGENT CHEMICALS IN AIR

Much of the public concern about incineration is based on the perception that incinerators emit chlorinated dioxins and furans, heavy metals, and other toxic substances into the atmosphere, potentially harming both the workforce and the public. The normal practice at the incineration-based disposal facilities has been to monitor only agent and carbon monoxide, carbon dioxide, nitrogen oxides (NO_x), and oxygen in the stack gas to determine that the incinerator is operating properly and that combustion is nearly complete. Other nonagent stack emissions are analyzed only during trial burns required to obtain or modify operating permits. The Stockpile Committee has extensively reviewed the trial burn emissions data from both JACADS (NRC, 1994c) and TOCDF (NRC, 1999a) and determined that emissions of organic and metallic species are exceptionally low when the incinerators and their pollution abatement systems are operating as designed.

The committee has recommended that the Army consider periodically monitoring emissions for species other than agent during normal operations as a means of reassuring disposal facility workers and the public that they are not being exposed to unacceptable risk (NRC, 1994b). This issue is likely to become more important since the Environmental Protection Agency (EPA) issued a draft document indicating that one potential incinerator emission, the most potent form of dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin), is considered to be significantly more toxic than was previously thought (EPA, 2000). Regular analyses for heavy metals (e.g., Hg, Pb, etc.) should also be considered. The Army has agreed to design and assess a plan for periodic monitoring of SOPCs in stack emissions at TOCDF, but this plan has not yet been finalized or implemented.

In addition to emissions from combustion processes, other potential sources of airborne compounds from

[1]The agent contamination levels 1X, 3X, and 5X are defined on Page 1 of Department of Army Pamphlet 385-61, Chemical Agent Safety, Chapter 5 (*http://www.usapa.army.mil*) (U.S. Army, 1997b). 1X indicates the item has been partially decontaminated. 3X indicates that it has been surface decontaminated by locally approved procedures and bagged or contained in an agent-tight container whose headspace analysis shows concentrations of agent higher than 0.0001 mg/m^3 for GB, 0.00001 mg/m^3 for VX, or 0.003 mg/m^3 for mustard. 5X indicates that an item has been completely decontaminated and may be released for general use or sold to the general public in accordance with all applicable federal, state, and local regulations.

ordinary facility activities, such as painting and welding, could be hazardous to workers. For instance, during construction of the plant at Umatilla, there was an incident in which a number of employees were treated for respiratory distress and sent to the emergency department. The chemical substance(s) responsible could not be identified, but this incident illustrates the potential for exposures to hazardous chemicals other than agent.

AGENT BREAKDOWN PRODUCTS AND CONTAMINANTS IN LIQUIDS

In addition to monitoring for mustard and VX that may remain in the hydrolysates produced at Aberdeen and Newport, respectively, monitoring must also measure the more toxic agent breakdown compounds that remain after hydrolysis. Because hydrolysis by aqueous caustic or hypochlorite solution is the method used for agent decontamination throughout the CSDP, all sites should consider this possible exposure source. Physical properties of the three most important agents and their major hydrolysis products (listed below each agent) are shown in Table 2-3, along with CAS (Chemical Abstracts Service) registry numbers, chemical formulas, and molecular weights. As the table shows, the hydrolysis products have lower molecular weights, lower vapor pressures, and generally higher water solubilities than the agent being hydrolyzed. The decreasing lipophilicity (preference for oil over water) can be seen in the more negative values of log K_{ow} (where K_{ow} is the equilibrium constant for partitioning a species between octanol and water) of the hydrolysis products.

A brief review of the chemistry of agent hydrolysis is presented below based on information and figures from *The Sources, Fate, and Toxicity of Chemical Warfare Agent Degradation Products* (Munro et al., 1999). Figure 2-1 shows a simplified scheme for the hydrolysis of GB. The P-F bond is hydrolyzed more rapidly than the P-OR bond; the P-C bond is much more resistant to hydrolysis. The scheme is oversimplified because most nerve agents are typically only 90 to 95 percent pure; they contain stabilizers, impurities from manufacturing, and other compounds that have formed during storage. For example, because GB is sensitive to both hydrolysis and acid-catalyzed decomposition, N-N′-diisopropyl carbodiimide and tributyl amine have been added as stabilizers. The carbodiimide reacts with water even more rapidly than GB, yielding a urea, as shown in Figure 2-2.

Figure 2-3 shows the simplified hydrolysis of VX. The two pathways correspond to initial hydrolysis of (1) the P-SR bond, which produces 2-diisopropyl ethyl mercaptoamine (DESH) and ethyl methylphosphonic acid (EMPA), and (2) the P-OR bond, which produces EA-2192 and ethanol. The upper path is favored at pH > 10. EA-2192 hydrolyzes more slowly than VX and is still very toxic (Munro et al., 1999). Further hydrolysis of EA-2192 produces DESH and methylphosphonic acid (MPA). The Army is currently working on analytical methods of quantifying low levels of VX in hydrolysate, but at this point an efficient, sensitive, rapid method has not been developed and demonstrated (NRC, 2000a). The Stockpile Committee has previously recommended that the Army increase its efforts to develop innovative analytical techniques with sufficient specificity, sensitivity, and speed for analyzing VX and mustard hydrolysate matrices for process monitoring under operational conditions (NRC, 2000a).

Figure 2-4 shows the major hydrolysis pathways for mustard, which are complicated by the reversible reactions of sulfonium ion and hemimustard with thiodiglycol to produce sulfur mustard thiodiglycol aggregate and hemimustard thiodiglycol aggregate. A further complication is the related formation of polymeric sludge. The low solubility of mustard in water and related high-molecular-weight compounds means that hydrolysis may be mass-transfer limited and, therefore, may require effective mixing to proceed to completion.

Currently, no monitoring program has been developed for agent degradation products. The assumption has been that breakdown products from decontamination or other activities are either less toxic or less persistent, or both. However, a recent evaluation prepared by the Army's Center for Health Promotion and Preventive Medicine and Oak Ridge National Laboratory has noted that a primary VX hydrolysis product, EA-2192, is more stable in water and is nearly as toxic as VX (Munro et al., 1999). Although EA-2192 may primarily be a concern for operations at Newport (where bulk VX will be destroyed by hydrolysis), it may also be present at other facilities if it survives normal VX decontamination operations.

Sulfur mustard is a known human carcinogen, and some of its degradation products may also be carcinogenic (IOM, 1993). Sulfur mustard acts as a vesicant or blister agent and shows acute systemic toxicity in addition to its effects on skin, eyes, and the respiratory tract.

TABLE 2-3 Physical Properties of Agents and Major Hydrolysis Products[a]

Army Name Abbreviation	Chemical Name	CAS Registry Number	Formula	Mol. Weight	Boiling Point (°C)	Freezing Point (°C)	Vapor Pressure (mm Hg @ 25°C)	Volatility (mg/m^3 @ 25°C)	Viscosity (cP)[b]	Density (g/cc @ 20°C)	Solubility (g/L H_2O @ 25°C)	Log K_{ow}[c]	$\Delta H_{comb.}$ (cal/g)[b,d]
Sarin (GB)	Isopropyl methylphosphonofluoridate	107-44-8	$C_4H_{10}FO_2P$	140.1	158	–56	2.9[b]	22,000	1.28 @ 25°C	1.102	Infinite	0.299	5.55
IMPA	Isopropyl methylphosphonic acid	1832-54-8	$C_4H_{11}PO_3$	138.1			0.0034				4.8		
MPA	Methylphosphonic acid	993-13-5	CH_5PO_3	96.0	Dec[e]	108.5	0.000002				>1000	–2.28	
VX	O-Ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothioic acid	50782-69-9	$C_{11}H_{26}NO_2PS$	267.4	298 Dec[e]	–39	0.0007	10.5	12.3 @ 20°C	1.008	30	2.09	8.33
EA-2192	S-(2-Diisopropylaminoethyl)methyl-phosphonothioic acid	73207-98-4	$C_9H_{22}NSPO_2$	231.3							Infinite	0.96	
DESH	Diisopropyl ethyl mercaptoamine	5842-07-9	$C_8H_{19}NS$	161.3	184[f]		1.5[f]		5.4 @ 20°C[f]	1.08[f]			
EMPA	Ethyl methylphosphonic acid	1832-53-7	$C_3H_9PO_3$	124.1			0.00036				180	–1.15	
MPA	Methylphosphonic acid	993-13-5	CH_5PO_3	96.0	Dec[e]	108.5	0.000002				>1000	–2.28	
Mustard (H or HD)	Di-2-chloroethylsulfide	505-60-2	$C_4H_8C_{l2}S$	159.1	215-217	13-14	0.11	920	3.95 @ 20°C	1.27	0.92	1.37	4.5
TDG	Thiodiglycol	111-48-8	$C_4H_{10}SO_2$	122.2	282[f]	–16[f]	0.00002		62.5[f]	1.18	Infinite	–0.77	

[a]Data from Munro et al.,1999, unless otherwise noted.
[b]Data from NRC, 1994b.
[c]K_{ow} is the partition coefficient (concentration ratio at equilibrium) for the compound in a two-phase system containing 1-octanol and water.
[d]$\Delta H_{comb.}$ is the heat of combustion (cal/g).
[e]Decomposes.
[f]Values from R. Ward, Aberdeen, personal communication. Properties for DESH are estimates from ASPEN PLUS.

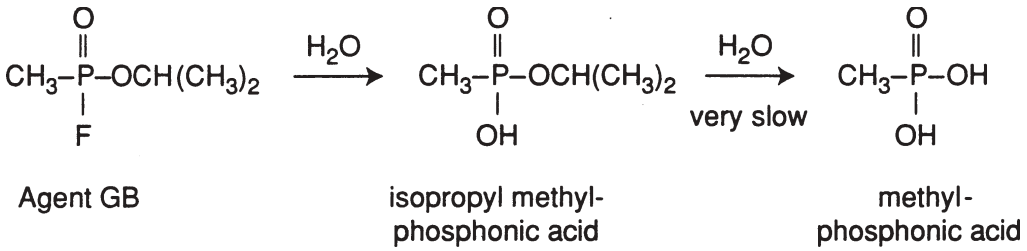

FIGURE 2-1 Simplified scheme for the hydrolysis of GB.
Source: Munro et al., 1999.

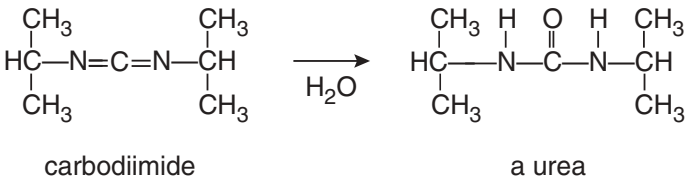

FIGURE 2-2 Hydrolysis of stabilizer N-N′-diisopropyl carbodiimide.

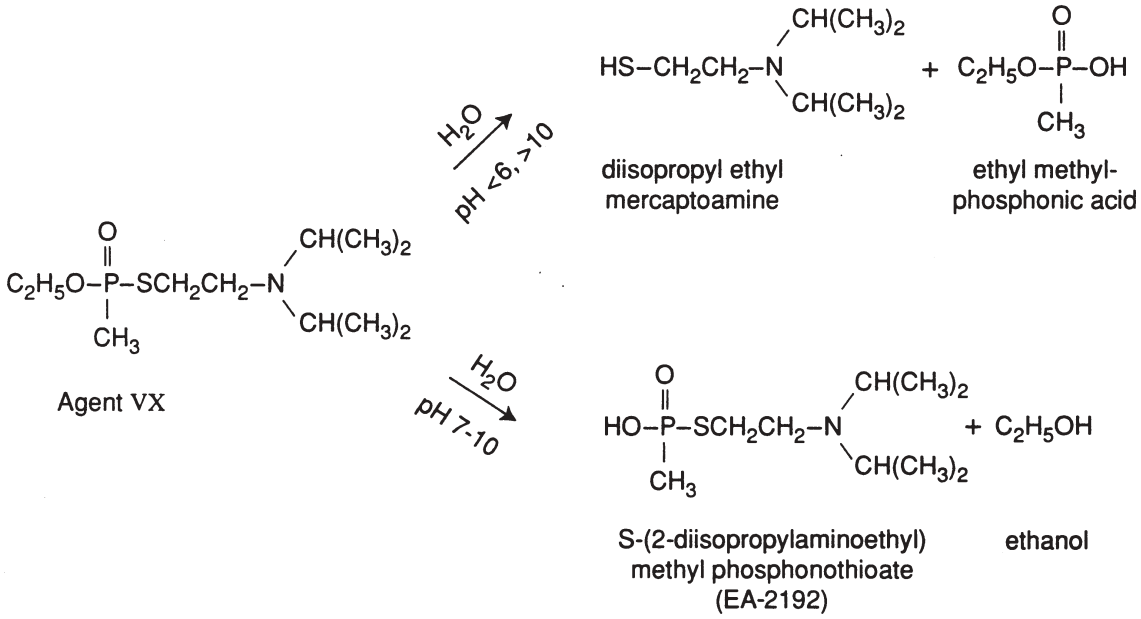

FIGURE 2-3 Simplified scheme for the hydrolysis of VX.
Source: Munro et al., 1999.

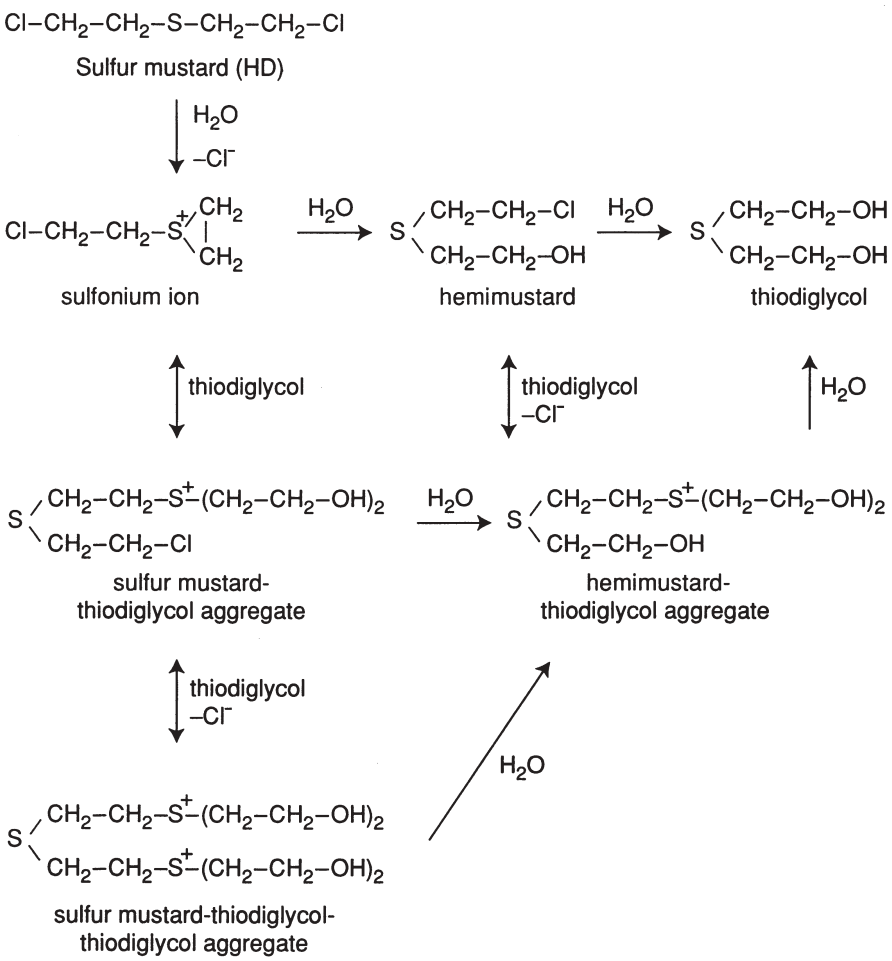

FIGURE 2-4 Major hydrolysis pathways for mustard.
Source: Munro et al., 1999.

Some HD degradation products retain considerable toxicity, including, in some cases, vesicant action. Examples include mustard and hemimustard-thiodiglycol aggregates, mustard sulfone, and divinyl sulfone (Munro et al., 1999).

A more complete description of the hydrolysis reactions involving these and other chemical agents and of the toxicities of the products can be found in Munro et al. (1999). Impurities found in ton containers of mustard at Aberdeen include 1,2-dichloroethane, trichloroethylene, tetrachloroethylene, 1,1,2,2-tetrachloroethane, and hexachloroethane, all of which may be subject to state and federal hazardous waste regulations (Munro et al., 1999). The Army's current plan is to

adsorb these chlorinated hydrocarbon compounds on activated carbon and send them to an off-site contractor for disposal.

SOLIDS CONTAMINATION: SPECIAL CONSIDERATIONS RELATED TO CLOSURE

Solid secondary wastes that are known or suspected to be contaminated with agent—such as activated carbon, DPE suits, and tools—must be safely disposed of during operations and closure. Contaminated soils and concrete, particularly concrete from the MDB, will be a concern during closure. The Army's standard method of determining the level of agent contamination on solids is to put them into a closed drum or other vessel at 70ºF, wait four hours, and analyze for agent in the head space (U.S. Army, 1997a). Although this procedure may be acceptable for contaminated steel or DPE suits, it may not be satisfactory for contaminated carbon, soil, or concrete, where the strong adsorption of agent may reduce vapor pressures to values much lower than would be expected for an equilibrium between liquid and vapor. Furthermore, as currently practiced, this procedure does not detect any agent breakdown products of potential concern.

The application of ion-trap secondary ion mass spectrometry (IT-SIMS) for the analysis of VX and its breakdown products on soil and concrete and the analysis of 2-chloroethylethyl sulfide (a simulant for HD mustard) on soil have been described in recent literature (Groenewold et al., 1995, 1998, 1999, 2000). IT-SIMS has the advantages of requiring a very small sample size (only milligrams of solid) and no solvent extraction. The method can identify breakdown products, as well as agents. The development of this method or a comparable advanced surface analysis technique to screen solid samples rapidly and sensitively for agent or toxic agent breakdown products could significantly improve detection and decrease the chances of worker exposure during some routine chemical demilitarization operations and many facility closure procedures.

3

Health Monitoring

This chapter discusses CSDP monitoring of employee health status as it relates to the workplace. A responsible industrial operation involving hazardous substances must have an effective occupational and environmental health program to monitor workers for health effects that might result from unknown exposures to chemical or physical agents during normal operations or from accidental exposures during upset conditions.

Based on recent Stockpile Committee reviews of the operational history of the incinerator-based chemical disposal operations at JACADS and TOCDF (NRC, 1999a) and the integrated designs for the liquid-based processing technologies at Newport and Aberdeen (NRC, 2000a), the Army has clearly made significant efforts to design safe systems at both types of facilities. Moreover, it is also apparent from these reviews that the Army has instituted mechanisms and procedures for operating these facilities in ways that minimize worker exposures to harmful substances.

In this chapter, the occupational and environmental health programs at JACADS, CAMDS, and TOCDF, and, by extension, those planned for the additional seven sites, are reviewed and evaluated.

FUNCTION OF AN OCCUPATIONAL AND ENVIRONMENTAL HEALTH PROGRAM

The function of an occupational and environmental health program is to protect and promote the health and safety of employees and to protect the public and the environment from hazards that may arise from industrial activities. The primary focus of occupational and environmental medicine is on the prevention of occupational injuries and illnesses, rather than on treatment, and on the prevention of occupationally related harm to public health and the environment.

The goal of employee health monitoring is to ensure that measures to protect the employee from workplace hazards are effective by carrying out medical surveillance programs for the early detection of adverse health effects. The types of chemical or physical hazards encountered determine the nature of the medical surveillance or health monitoring programs.

Monitoring employee health is one part of the exposure assessment in the risk assessment paradigm. The second part is workplace monitoring, the subject of Chapter 2 of this report.

The practice of occupational and environmental medicine relies on the profession of industrial hygiene to assess the effectiveness of procedures, including work practices, engineering controls, and personal protective equipment, for protecting employee health. The degree and type of worker protection required during operations involving chemicals are based on available toxicity information for the substances involved. Generally, this information is obtained from studies on laboratory animals. However, human data may also be available, especially for chemicals that have been in use for some time; in the case of chemical warfare agents, for example, there is a fairly extensive animal and human exposure database that is regularly reviewed and assessed (NRC, 1997b, 1999c). Physical hazards, such as noise, heat, vibration, radiation of vari-

ous types, and repetitive motion, must also be considered in protecting employee health.

To ensure that employee health is being protected, physicians and others engaged in occupational and environmental medicine conduct medical surveillance programs that address the types of hazards involved in the work situation. Occupational physicians may also use epidemiological studies to assess the effectiveness of employee health protection programs. Physicians practicing occupational medicine require appropriate training, not only in this field, but also in clinical practice and related fields, such as industrial hygiene, toxicology, and epidemiology; they also work closely with industrial hygienists, engineers, and health physicists. Physicians in occupational and environmental medicine must also be aware of applicable laws and regulations.

A Generic Program

In 1992, the American College of Occupational and Environmental Medicine (ACOEM) issued a statement on the scope of occupational and environmental health programs and practice (ACOEM, 1992). The essential components of this detailed statement are summarized below.

Health Evaluation of Employees

Health evaluations of employees fall into three general categories:

- *Preassignment.* The health status of new or current employees should be determined before recommending work assignments to ensure that workers are capable of performing the job safely and without harming others.
- *Periodic medical surveillance.* The health status of employees should be reviewed periodically to ensure that no work-related illnesses have developed. Reviews may be limited to appropriate organ(s) or organ system(s). The frequency of reviews is related to the potential hazard(s).
- *Post-illness or post-injury review.* The health status of an employee should be reviewed after a prolonged illness or injury to ensure that the employee is capable of returning to work safely and that, if necessary, the work assignment can be adjusted until recovery is complete.
- *Termination or postemployment exams.* Although not specifically included as an essential component of an occupational health program by ACOEM, termination or postemployment exams establish a record of postemployment health status.

The results of every evaluation should be communicated to the employee whether or not abnormalities were detected. When appropriate, follow-up evaluation and/or treatment should be arranged with the employee's own physician.

Diagnosis and Treatment

Occupational illnesses and injuries should be diagnosed and treated promptly. The occupational physician, who is familiar with workplace hazards, is uniquely qualified to recognize work-related conditions and should be able to arrange for prompt treatment and rehabilitation.

Emergency Treatment of Nonoccupational Injuries or Illnesses

The occupational medicine program should provide emergency treatment for employees at work. Treatment of nonoccupational conditions may be palliative (i.e., preventing loss of life and limb and keeping the patient comfortable) until more definitive care can be obtained.

Education of Employees

Employees should be fully informed of the potential hazards associated with their jobs. Regulations, such as the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard, require that hazard information be communicated not only to employees, but also to users of manufactured products (OSHA Standard 29 CFR 1910.1200 Hazard Communication). Information is communicated partly through material safety data sheets and labels. Education and training of employees about health hazards they may encounter on the job, along with appropriate protective measures, should be conducted by a multidisciplinary health team of relevant specialists and trained health educators.

Programs for Personal Protective Devices

The occupational and environmental health program should ensure that programs are in place for fitting

employees with personal protective equipment and training them in its proper use and maintenance. Programs are required by OSHA standards, such as the standard for respiratory protection (OSHA Standard 29 CFR 1910.134 Respiratory Protection). Personal protection devices may include earplugs, earmuffs, safety glasses, and respirators.

Evaluation, Inspection, and Abatement of Workplace Hazards

Occupational health personnel should familiarize themselves with the workplace, inspect it regularly, know the jobs and their potential hazards, and make recommendations for mitigating hazardous situations.

Toxicological Assessments

Occupational health personnel should be familiar with toxicity information on chemicals handled in the workplace. If the information appears to be inadequate, recommendations should be made for obtaining additional information.

Biostatistics and Epidemiological Assessments

Data on employee work experiences and potential chemical exposures of workers and the public should be gathered and retained, and when appropriate should be used for epidemiological studies to determine whether any exposures have caused illness. Information obtained from these studies can be useful in ensuring that adequate health standards are in place to protect employees and the public.

Maintenance of Occupational Medical Records

Occupational medical records should record and document occupationally related medical information of all types (e.g., medical examinations, visits to medical facilities [even for nonoccupational reasons], clinical laboratory data, injuries, pulmonary function tests, audiograms, etc.). The period of time that records must be retained is specified by law depending on the type of data and the health-related agent(s) of concern. In most cases, OSHA requires that information be retained for at least 30 years after the termination of employment (OSHA Standard 29 CFR 1910.1020 Access to Employee Exposure and Medical Records). Medical records should be kept in compliance with the OSHA standard, but access to the records should be restricted to health care professionals, the employee and his/her designee, and appropriate certifying/reviewing officials. Release of an individual's medical information must be authorized in writing by that individual.

Immunization Against Possible Occupational Infections

Protection must be provided to employees against infections for which effective immunizations are available.

Development of Government Health and Safety Regulations

Occupational health personnel are uniquely qualified to assist in the interpretation and development of regulations as they relate to the workplace and the local community.

Periodic Evaluations of the Occupational and Environmental Health Program

Regular evaluations of the program are necessary to ensure that it meets its objectives.

Disaster Preparedness Planning

Occupational health personnel should work with community personnel in preparing for emergencies in the workplace, as well as for accidental releases from the plant that might affect the local community. Preparations are required by Title III of the Superfund Amendments and Reauthorization Act (1986).

Rehabilitation of Employees with Alcohol and Drug Dependencies or Emotional Disorders

Occupational physicians recognize the importance of trying to rehabilitate employees who have problems with drug and alcohol abuse. This must be done in a confidential manner. Some types of work, such as transportation or military activities, have mandatory drug screening and rehabilitation programs.

ACOEM's statement on the scope of occupational and environmental health programs and practice also includes "elective components of occupational and environmental health programs." These might be thought of as desirable but nonessential components of the pro-

gram. These elective components are described briefly below:

- palliative treatment of disorders to enable an employee to complete the work shift or for conditions for which an employee may not ordinarily consult a physician
- repetitive treatment of nonoccupational conditions prescribed and monitored by the employee's personal physician (e.g., physiotherapy, routine injections, etc.), if the employee's personal physician approves
- controlling illness-related absences from the job
- assistance in evaluating personal health care
- immunization against nonoccupational infectious diseases
- health education and counseling (e.g., mental health, hypertension control, smoking cessation programs, etc.)
- termination and retirement administration
- participation in planning, providing, and assessing the quality of employee health benefits
- participation in systematic research

An essential element of any medical program is informed patient consent prior to the performance of any test or procedure. Although informed consent is not specifically mentioned in the ACOEM components of occupational and environmental health programs, it is inherent in the ethical practice of medicine. The ACOEM Code of Ethical Conduct (adopted October 25, 1993) states that physicians should "relate honestly and ethically in all professional relationships." Also, the Association of Occupational and Environmental Clinics has issued guidance relative to patient consent, confidentiality of medical records, and communication of the results of tests and procedures (AOEC, 1987).

CHEMICAL STOCKPILE DISPOSAL PROGRAM OCCUPATIONAL HEALTH PROGRAM

Overview

Workers in the Army's CSDP face many of the same kinds of workplace health hazards as workers in the chemical industry. The greatest differences are the unique designation of the species being destroyed as chemical warfare agents and the adverse publicity and negative emotions associated with them. The following areas present special challenges:

- rigid controls required to prevent employee and public exposure to chemical agents
- rapid response required if an agent is released, especially if exposure of employees or the public has occurred or is anticipated
- use of multiple contractors (on site and across all sites) to run various aspects of operations utilizing different medical forms and procedures
- the frequent use of OSHA level A or B ensembles, which can cause heat stress, especially in warm weather
- public concerns about having chemical agent disposal facilities nearby
- the high levels of security required around chemical agent storage sites and disposal facilities
- detailed, frequent communications with the public and local emergency planning officials after a chemical agent release
- the personnel reliability program (PRP)[1]
- frequent audits necessitated by the administrative requirements associated with handling chemical agents and munitions

Assessment and Evaluation

Stockpile Committee members visited both JACADS and TOCDF/CAMDS between June 1999 and October 2000 to review the chemical monitoring and occupational health program at each site and interview site managers and operations personnel. During this same time period, the committee requested and received numerous detailed briefings on the philosophy, implementation, and effectiveness of these programs from senior Program Manager for Chemical Demilitarization (PMCD) personnel responsible for designing and overseeing program-wide monitoring, industrial hygiene, and occupational health programs. Committee members also interviewed Dr. Roger G. McIntosh, vice president and manager, Emergency Medical Training and Preparedness Division, Science Applications International Corporation, the Army's contractor responsible for overseeing the provision of occupational health services for the CSDP.

[1]The personnel reliability program (PRP) is a Department of Defense program designed to ensure that each individual whose duties are associated with chemical agents meets the highest standard of personal reliability.

At JACADS and TOCDF, committee members met with members of the occupational and environmental health teams, including the clinic medical directors, nurses, and industrial hygienists. Each person described his or her role in the program and answered the committee's questions. The committee observed normal operations of the clinic and reviewed relevant Army and contractor documents, including generic and site-specific forms and regularly used medical and industrial hygiene forms. One anonymous medical file was later reviewed by a committee member.

Three Army documents, *Generic Medical Support Plan* (U.S. Army, 1998a), *Generic Medical Implementation Plan* (U.S. Army, 1999b), and *Generic Medical Continuing Quality Improvement Plan* (U.S. Army, 1998b), provide detailed descriptions of the medical support functions at all CSDP sites. They also specify the policies, operational concepts, personnel requirements, and program elements necessary for the provision of medical support. The contractor medical director at each site is expected to use these documents as a guide to the development of site-specific medical implementation plans responsive to local policies and procedures.

These documents cover the following areas, which are governed in turn by numerous referenced OSHA and Army standards and regulations, as well as other federal and state regulations:

- staffing and training
- medical surveillance, including medical surveillance exams
- medical surveillance for chemical agent
- monitoring for heat stress
- keeping, releasing, and retaining medical records
- support for the alcohol and drug abuse program
- support for hazardous waste operations
- support for the chemical PRP
- medical response to chemical accidents/incidents
- hearing conservation program
- support for the respiratory protection program
- support for the occupational vision program
- health education/communication about hazards, including reproductive and carcinogenic hazards
- treatment of on-the-job illnesses and injuries
- epidemiological investigations
- health care administration, including establishment of a quality improvement plan
- industrial hygiene services
- protection of patients' rights and responsibilities

Emergency treatment of nonoccupational injuries and illnesses is also provided, although it is not specifically referred to in these documents.

The *Generic Medical Implementation Plan* also specifies that the systems contractor's quality assurance unit must conduct regular audits of the systems contractor's occupational health program and that an annual audit of the program must be conducted by PMCD-designated health care professionals. Reports of all audits are forwarded to the clinic medical director and the medical administrator for prompt action. Nonconformance requires a written plan for corrective action.

Similar site-specific documents reviewed at JACADS included *Occupational Health and Hygiene Plan* and *Medical Surveillance Program* (U.S. Army, 1997c, 2000c). Both documents cover essentially the same areas as the Army's generic plan but include modifications to meet site-specific needs. Site-specific documents for medical procedures were also reviewed at TOCDF. These included *Medical Surveillance for Potential Agent Exposure* and *Cholinesterase Monitoring Program* (U.S. Army, 1996b, 1999d). These documents are specific to the medical surveillance program for chemical agents. Several other documents relative to the heat-stress prevention program at JACADS and TOCDF were reviewed, as well as the quality improvement plan (U.S. Army 1998c, 1999b).

The Army's CSDP includes all of the essential components recommended by ACOEM for an occupational and environmental health program except for participation in the development of government health and safety regulations. The lack of Army involvement in this area is appropriate because this is an industry regulatory activity. Several of the nonessential program components recommended by ACOEM, such as palliative treatment of disorders to enable a worker to complete a work shift and to obtain health education and counseling, are included in the Army's program.

The Army also provides in-depth training for all personnel involved in the occupational and environmental health program. One committee member attended the Toxic Chemical Training Course for Medical Support Personnel given at Edgewood, Maryland, in April 2000. The course lasted one week and covered all aspects of the Army's occupational and environmental health program. An exam was given at the end of the course, which was approved for continuing education credit. The quality of the presentations and the instructional materials was excellent.

Based on the committee's review of the Army's

CSDP occupational and environmental health program, the committee believes that the program described in the referenced documents has been fully implemented and that medical records are being maintained as prescribed. The committee noted that medical surveillance for chemical agents and heat-stress prevention programs are carried out rigorously. The committee concluded that the program is comprehensive, professional, and adequate to meet the known occupational health needs of CSDP workers.

DEVELOPMENTS IN MEDICAL DIAGNOSTIC TECHNIQUES

Advances in biotechnological diagnostic techniques are likely to provide more sensitive methods of detecting very low levels of exposure to some chemicals. As these new techniques become commercially available, the PMCD should consider adding them to the medical surveillance program.

For example, recent research has shown that adducts of deoxyribonucleic acid (DNA) and proteins are formed on exposure to a number of chemicals, including aromatic amines, polycyclic aromatic hydrocarbons, and a variety of alkylating agents (Skipper and Groopman, 1991). These adducts, which are often present in blood and urine and thus are easily accessible, are formed even at very low exposure concentrations. Therefore, they sometimes provide a more sensitive measure of exposure than current methods. However, they should not be used as screening tools for predicting adverse health effects in humans until the correlation between exposure and health effects is better known. Preventing exposure is still the key to avoiding adverse health effects.

The major chemical warfare agents include vesicants, such as HD, and nerve agents, such as GB and VX. All of the vesicants are alkylating agents and, therefore, will yield adducts with both DNA and proteins, which could serve as the basis for very sensitive assays for exposure (nerve agents are alkylphosphonic esters and are not especially reactive with macromolecules like DNA and proteins). The PMCD should continue to follow and evaluate developments in medical diagnostic techniques and incorporate them into the CSDP medical monitoring program.

4

Data Utilization and Records Management

Data generated by workplace monitoring programs and activities are immediately useful as real-time, or near-real-time, indicators of exposure to chemicals of concern and as operational tools for mitigating risk and facilitating operating decisions. In addition, monitoring data collected and stored in a readily accessible form can provide a basis for a variety of other analyses. For example, cumulative monitoring data can be used to document the frequency and magnitude of chemical releases and/or exposures.

DATA REQUIREMENTS

Several CSDP documents require the establishment and maintenance of on-site databases. PMCD's *Monitoring Concept Plan* requires that personnel maintain documentation of all monitoring activities during operations, including daily logs of air monitoring, equipment calibration, maintenance, inspections, and agent responses, as well as sample records, standard operating procedures for air monitoring and laboratory analysis, authorizing signatures, and other documentation (U.S. Army, 1997a).

The ACAMS laboratory is required to transmit the electronic file and the results of data collection to the laboratory project officer. Routine ACAMS parameters are tracked and maintained by the disposal facility laboratory according to site-specific protocols. The same is true for DAAMS analyses.

In addition to a site-specific agent monitoring plan and related documentation, the *Monitoring Concept Plan* requires that the laboratory at each site develop a site-specific monitoring plan for the continuous emission monitoring system (CEMS) and specifies the documentation and data parameters this plan must address (U.S. Army, 1997a). For instance, at TOCDF, the CEMS monitoring plan addresses continuous monitoring of carbon monoxide, carbon dioxide, and oxygen in exhaust sampled from each incinerator/furnace; NO_x emissions are only sampled from exhaust from the common stack (EG&G, 1994). Routine CEMS data are generated and maintained in accordance with records requirements in the PMCD Quality Assurance Program Plan (QAPP) for all of the CEMS at each facility (EG&G, 1994). Data parameters are forwarded to the laboratory project officer upon request.

The CSDP *Generic Medical Support Plan* states that the CSDP medical director is the custodian of medical records for CSDP workers (U.S. Army, 1998a). The records, which are considered private and confidential information, must be complete enough to provide data for use in health maintenance and treatment, epidemiological studies, and government and contractor program evaluations. Medical records must identify the patient, support the diagnosis, justify the treatment, and document follow-up care or referrals. Record keeping for employees in the nerve agent or mustard agent medical surveillance programs is described in the Army pamphlets *Occupational Health Guidelines for the Evaluation and Control of Occupational Exposure to Nerve Agents GA, GB, GD and VX* and *Occupational Health Guidelines for the Evaluation and Control of Occupational Exposure to Mustard Agents H, HD and HT* (U.S. Army 1990, 1991). Screening of medical

records for the chemical personnel reliability program is based on Army regulation *Nuclear and Chemical Weapon and Materiel Chemical Surety* and procedures described in Army regulation *Medical Services Medical Record Administration and Health Care Documentation* (U.S. Army, 1995; 1999e). Employee exposure records are kept in compliance with OSHA Standard 29 CFR 1910.1020, Access to Employee Exposure and Medical Records.

The PMCD *Generic Medical Implementation Plan* stresses the importance of accurate record keeping for an efficient and reliable health education and surveillance program (U.S. Army, 1999b). Each employee's health history, including confidential information, is used to track his or her health status. Therefore, records must be legible, accurate, and professional. Access to records is restricted to health care professionals, the employee and his/her designee, and appropriate certifying officials. Information in individual medical records can be released only after a signed and dated "Authorization for Release of Medical Records" has been received by the medical staff. Information concerning an employee's reliability and ability to perform work safely may be conveyed to the employee's supervisor and the certifying official without a signed written consent form.

Finally, PMCD work permits must be issued for all entries into chemical agent hazard areas and areas designated "Permit Required Confined Spaces." Work permits, which must identify the individual and the work to be performed, are reviewed by operations maintenance and safety personnel and approved by the shift manager. Special monitoring may be required, and records of entries and monitoring must be kept for 30 years beyond the last day of employment or the closure date of the facility.

The extensive data collected via ACAMS and DAAMS are captured and stored in electronic form with total redundancy. However, they can only be immediately accessed at the operating site, making analyses at the programmatic level difficult. As additional sites become operational, the capability of reviewing and analyzing agent monitoring data from several or all sites at the programmatic level could be useful.

Data generated by nonagent CEMS instruments are recorded both on chart recorders and electronically for transmission to the process data acquisition recording (PDAR) system for recording on magnetic disks (EG&G, 1994). Data are archived both as hard copy (e.g., instrument service logbooks, recorder charts, calibration forms) and electronically on disk. At TOCDF, hard copies are maintained by the Monitoring Branch for three months and then sent to the TOCDF Document Control Center, where they are stored until the Utah Department of Environmental Quality gives its permission for the data to be recorded on microfiche and transferred to a government archive. Electronic data are maintained on disks in the plant control room for 45 days. Disks are then transferred to the Document Control Center, where they are stored until approval is received to transfer them to a government archive (EG&G, 1994). As additional sites become operational, it may be useful for all emissions data to be accessible electronically for analysis on a program-wide level.

Current management of data from worker monitoring is governed by a number of guidelines and regulations, the purpose of which is to ensure that a thorough exposure and treatment history is maintained for all CSDP employees. A review of the guidelines and requirements, and discussions with PMCD medical staff, indicated that most employee monitoring records are maintained in paper form at the employment site during active employment but are moved to archival records storage facilities when the employee leaves the site. Once records have been archived, they can only be recovered through a laborious manual search according to the employee's name. Therefore, it would be difficult to use worker monitoring data for program-level analyses or other studies.

CORRELATING TIME/ACTIVITY AND CHEMICAL CONCENTRATION RECORDS

One method of reconstructing worker exposure to a harmful chemical is to correlate location data from shift duty records, hazardous operations records maintained by the industrial hygiene program, and toxic area entry work records with area airborne agent or industrial hygiene workplace survey records. Indeed, correlating activity pattern data with measurements or estimates of chemical, biological, or other environmental contaminants has been identified by the NRC as an effective method of estimating the level of exposure to harmful substances sustained by deployed U.S. military personnel (NRC, 2000c). However, retrospective analyses of this type are difficult or impossible to conduct if activity and chemical monitoring records are not archived or are only available in paper files. Reconstructing the exposure history of an individual worker who was employed at two or more chemical disposal facilities, pos-

sibly managed by different contractors using different record forms and content, could be a daunting task. Electronic records with a common format could make retrospective analyses much more feasible.

EMPLOYEE HEALTH INFORMATION AND WORKPLACE MONITORING DATA

Health effects studies, such as epidemiological studies, utilizing employee health records require that the records be complete, well maintained, and readily accessible, and that they contain comparable information. These requirements apply to records for all sites. Therefore, automation and centralization of the records is practically a necessity. Records from multiple CSDP sites with multiple contractors at each site may be kept in a variety of forms and according to a variety of procedures. Standardized forms and procedures for all sites would ensure that records could be used for health effects studies. Epidemiological studies on occupationally related diseases are most meaningful when employee exposure data are available for correlation with the health data. Complete, high-quality health and exposure data would help ensure the validity of the study results.

STANDARDS FOR ELECTRONIC DATABASES

If the Army decides to create a programwide electronic database for tracking worker monitoring, guidance provided in three National Standards published by the American Society for Testing and Materials could be applicable:

- E 1769-95 Standard Guide for Properties of Electronic Health Records and Record Systems
- E 1902-97 Standard Guide for Management of the Confidentiality and Security of Dictation, Transcription, and Transcribed Health Records
- E 1384-99 Standard Guide for Content and Structure of the Electronic Health Record

A database based on these standards could significantly raise the quality of the program-wide database, reduce start-up problems, and facilitate CSDP's attainment of worker protection standards.

5

Findings and Recommendations

The following findings and recommendations on occupational health and workplace chemical monitoring at CSDP facilities are based on the review described in Chapters 1 through 4 of this report.

Finding 1. Consistent with the Stockpile Committee's prior recommendation that the CSDP use technology that will minimize overall risk to the public and to the workers at each site, protecting the health and well-being of the workforce at chemical agent disposal facilities is an overarching priority, on a par with protection of the public health and safety.

Recommendation 1. The Army should continue to select technologies and implement programs at disposal facilities that ensure the expeditious disposal of the chemical agents and munitions stockpile and minimize overall risk to workers and the public at each site.

Finding 2a. Current workplace monitoring systems for chemical agents are generally adequate for normal operations but may have serious deficiencies during accidents or departures from nominal operating conditions. Potential employee exposures as a result of process upsets and/or accidents can be detected by existing monitoring systems, but not in real time.

Finding 2b. Currently, ACAMS and DAAMS data are available electronically, but only at the operating site where agent measurements were made.

Finding 2c. Advances in monitoring technology could reduce response times and/or false positive alarm rates and could possibly make simultaneous monitoring of different agents feasible. This could reduce the risk of worker exposure during both disposal and closure operations.

Finding 2d. Workplace monitoring for nonagent-related chemicals is conducted on an as needed basis as part of the industrial hygiene program.

Recommendation 2a. The Army should continue to pursue improvements in airborne agent monitoring, including improved ACAMS technology (for multi-agent monitoring and lower false alarm rates), and in methods for identifying interferents that cause false alarms. It should also pursue new analytical techniques that could lead to real-time agent detection.

Recommendation 2b. The Army should consider developing the capability of reviewing and analyzing agent monitoring data from several or all sites at the programmatic level.

Finding 3. Some chemical agent reaction products from surface hydrolysis or produced in liquid-phase process streams can be almost as toxic as the parent agent and more resistant to degradation. Standard technology used in routine operations for detecting the presence of agent generally does not detect decomposition

products. The possible presence of decomposition products during weapons processing or closure operations has received little attention to date.

Liquid-phase processing technologies will be used at the bulk-only sites (Aberdeen, Maryland, and Newport, Indiana), and surface hydrolysis products may be encountered during closure activities at all disposal sites. Therefore, analytical techniques must be capable of detecting both residual chemical agent and toxic chemical agent degradation (chiefly hydrolysis) products in liquids and in solids. Established techniques and analytical measurement practices for detecting agent and/or agent degradation products in liquid-phase matrices or associated with solid materials are not sensitive or rapid enough to provide the near-real-time process control or waste materials screening required for worker protection. The current techniques for analyzing headspace may be inadequate for detecting agent or agent degradation products associated with spent activated carbon or other absorptive materials. This extends the committee's previous recommendation to develop better detection methods for residual liquid-phase VX and mustard agents associated with the liquid-phase process streams planned for Aberdeen and Newport (NRC, 2000a).

Recommendation 3a. For better monitoring of liquid-phase process streams, the Army should actively pursue the development of more accurate and faster liquid-phase analytical techniques for detecting residual agent, as well as agent degradation products of concern.

Recommendation 3b. The Army should identify toxic agent reaction products likely to be present at potentially harmful levels in liquid-phase process streams, liquid wastes, and solid wastes, including waste streams generated during closure activities.

Recommendation 3c. The Army should develop and deploy advanced technologies for rapidly and accurately measuring residual agent and agent degradation products of concern associated with solid waste, particularly on solid waste surfaces and spent activated-carbon stocks encountered during closure operations.

Finding 4. The CSDP's overall occupational and environmental health program, as well as the specific versions implemented at JACADS and TOCDF, are comprehensive. That is, they include all of the required components, as well as some optional components, recommended by the American College of Occupational and Environmental Medicine. Based on committee briefings and discussions with PMCD and contractor site personnel involved in chemical monitoring, industrial hygiene, and occupational medicine, these programs appear to be staffed by competent professionals who understand the importance of their roles and appear to be fulfilling them responsibly.

Recommendation 4. The Army and its operating contractors should continue to execute and refine a vigorous, proactive occupational and environmental health program at all chemical agent disposal sites.

Finding 5. As disposal activities near completion, some workers will want to continue working in the CSDP at other sites. During visits to the operating TOCDF site and the construction sites at Anniston, Alabama, Aberdeen, Maryland, and Newport, Indiana, committee members encountered many veteran employees of JACADS both among contractor personnel and Army oversight personnel. The formatting and maintenance of workplace monitoring and worker medical records for contractor personnel are currently the responsibility of the prime operating contractor at each site. Consistent formats and methods of archiving these records would clearly facilitate the creation of career medical and potential exposure profiles for individuals who work at more than one disposal facility. An easily accessible database of records for all sites (subject to maintaining workers' privacy rights) would be extremely useful for epidemiological studies of health trends among CSDP workers.

A useful method of reconstructing potential worker exposure to agents can be to correlate data from records of shift duty, hazardous operations, toxic area entries, and area airborne agent concentrations. These correlations are only practical if the records are electronically archived and centrally searchable.

Recommendation 5a. The Army and its operating contractors should use the same medical forms, especially for key program elements, such as agent exposures and heat-stress monitoring.

Recommendation 5b. The Army and its operating contractors should retain medical records in a way that allows for continuity in the event personnel are transferred to other disposal facilities.

Recommendation 5c. The Army and its operating contractors should automate as much as feasible important medical information related to worker exposure to facilitate epidemiological studies. Automated information, available at the programmatic level, should include, but should not be limited to, results of medical examinations, evaluations of exposure to agents, measurements of cholinesterase levels, heat-stress data, and accident/injury information.

Recommendation 5d. The Army should consider requiring that electronic records relating to potential worker exposure to agent or other toxic chemicals be stored in a common format and be available at a programmatic level.

Finding 6. Ongoing analyses of worker medical data across disposal facilities could be a valuable tool for identifying and minimizing health threats to workers.

Recommendation 6a. The Army should provide summary facility and cross-facility statistics annually on the outcomes of key medical surveillance programs, such as programs for exposures to chemical agents and heat stress.

Recommendation 6b. The Army should thoroughly investigate the need and opportunities for population-based comparisons and/or epidemiological studies.

Finding 7. Just as advancing technology can be expected to provide better workplace chemical monitoring techniques, rapidly advancing biotechnology can be expected to provide more sensitive and specific methods of measuring worker exposure to harmful substances. For instance, adducts of DNA and protein formed by carcinogens that are alkylating agents, such as sulfur mustard, can now be detected at very low levels of exposure. Measurements of sulfur mustard adducts could be incorporated into the Army's medical surveillance program for assessing low-level exposures to blister agents. Future advances in genetics may provide new methods of screening for low-level exposures in individuals and populations.

Recommendation 7. The Army should keep abreast of, and adopt where appropriate, developments in medical diagnostic techniques for detecting and quantifying low-level exposures to toxic substances, including research related to the use of DNA and protein adducts as measures of toxicologically relevant metabolites.

References

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Appendixes

Appendix A

Reports by the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee)

Comments on Operational Verification Test and Evaluation Master Plan for the Johnston Atoll Chemical Agent Disposal System (JACADS) (1989)

Demilitarization of Chemical Weapons: On-Site Handling of Munitions (1989)

Demilitarization of Chemical Weapons: Cryofracture (1989)

Workshop on the Pollution Abatement System of the Chemical Agent Demilitarization System (Letter Report, May 1991)

Letter report on siting of a cryofracture chemical stockpile facility (August 1991)

Comments on Proposed Cryofracture Program Testing (Letter Report, August 1991)

Review of the MITRE Report: Evaluation of the GB Rocket Campaign: Johnston Atoll Chemical Agent Disposal System Operational Verification Testing, dated May 1991 (Letter Report, September 1991)

Review of the Choice and Status of Incineration for Destruction of the Chemical Stockpile (Letter Report, June 1992)

Letter report to recommend specific actions to further enhance the CSDP [Chemical Stockpile Disposal Program] risk management process (January 1993)

Recommendations for the Disposal of Chemical Agents and Munitions (February 1994)

Review of Monitoring Activities Within the Army Chemical Stockpile Disposal Program (April 1994)

Evaluation of the Johnston Atoll Chemical Agent Disposal System Operational Verification Testing: Part I (July 1993) *and Part II* (April 1994)

Evaluation of the Army's Draft Assessment Criteria to Aid in the Selection of Alternative Technologies for Chemical Demilitarization (December 1995)

Review of Systemization of the Tooele Chemical Agent Disposal Facility (March 1996)

Public Involvement and the Army Chemical Stockpile Disposal Program (Letter Report, October 1996)

Risk Assessment and Management at Deseret Chemical Depot and the Tooele Chemical Agent Disposal Facility (September 1997)

Using Supercritical Water Oxidation to Treat Hydrolysate from VX Neutralization (May 1998)

Carbon Filtration for Reducing Emissions from Chemical Agent Incineration (July 1999)

Tooele Chemical Agent Disposal Facility: Update on National Research Council Recommendations (November 1999)

Obstacles to Closure of the Johnston Atoll Chemical Agent Disposal System (Letter Report, May 2000)

Integrated Design of Alternative Technologies for Bulk-Only Chemical Agent Disposal Facilities (May 2000)

A Review of the Army's Public Affairs Efforts in Support of the Chemical Stockpile Disposal Program (Letter Report, November 2000)

Assessment of Supercritical Water Oxidation Technology Development for Treatment of VX Hydrolysate at the Newport Chemical Agent Disposal Facility (Letter Report, January 2001)

Appendix B

Biographical Sketches of Committee Members

PETER B. LEDERMAN (*Chair*), retired executive director of the Hazardous Substances Management Research Center and executive director of the Office of Intellectual Property, is a research professor of chemical engineering and environmental policy at the New Jersey Institute of Technology. He received his Ph.D. in chemical engineering from the University of Michigan. Dr. Lederman has 47 years of experience in all facets of environmental management, control, and policy development; hazardous substance treatment and management; and process engineering; he has more than 18 years of experience as an educator. He is a registered professional engineer and a diplomate of the American Academy of Environmental Engineers. Dr. Lederman has worked on environmental policy at the federal and state levels and has served on several National Research Council committees, most recently the Committee on Decontamination and Decommissioning of Gaseous Diffusion Plants.

CHARLES I. McGINNIS (*Vice Chair*) has an M.Engr. from Texas A&M University. After retiring from the U.S. Army as a major general and former director of civil works for the U.S. Army Corps of Engineers, he served in senior positions at the Construction Industry Institute in Austin, Texas. He was also director of engineering and construction for the Panama Canal Company and was subsequently vice president of the company and lieutenant governor of the Canal Zone. As director of civil works for the U.S. Army Corps of Engineers, he was responsible for a $3 billion per year budget for the planning, design, construction, operation, and maintenance of public works nationwide. He is a registered professional engineer in Texas and Missouri.

DAVID H. ARCHER, a member of the National Academy of Engineering, has a Ph.D. in chemical engineering and mathematics from the University of Delaware. He is a retired consulting engineer with the Westinghouse Electric Company and is currently adjunct professor at Carnegie Mellon University. Dr. Archer has worked in both industry (at Westinghouse as an engineer, supervising engineer, department manager, and consulting engineer) and academia (at the University of Delaware and Carnegie Mellon University for almost 10 years). He has considerable experience in research and management related to chemical engineering, as well as experience with combustion and plant management.

PIERO M. ARMENANTE has a Ph.D. in chemical engineering from the University of Virginia and is currently Distinguished Professor of Chemical Engineering at the New Jersey Institute of Technology and director of the Northeast Hazardous Substance Research Center, a seven-university center funded by the Environmental Protection Agency. Dr. Armenante's research interests include multiphase mixing in agitated systems, the biological treatment of hazardous waste, industrial sterilization processes, and biomedical engineering. He has an extensive list of peer-reviewed and other publications and has administered numerous grants, studies, and projects.

JERRY L.R. CHANDLER has a Ph.D. in biochemistry from Oklahoma State University and has done extensive postgraduate study in mathematics. He is currently a research professor at the Krasnow Institute for Advanced Study at George Mason University, Fairfax, Virginia. Earlier in his long career, Dr. Chandler served with the U.S. Public Health Service, the National Institute for Occupational Safety and Health (NIOSH), the Food and Drug Administration, and the National Cancer Institute Epidemiology Program. More recently, he was a neuropharmacologist in the Epilepsy Branch of the National Institute of Neurological Disorders and Stroke of the National Institutes of Health. Dr. Chandler is a founding member and president of the Washington Evolutionary Systems Society and has published extensively on using mathematical category theory to understand the origins of disease. He previously served as a NIOSH observer with the National Academy of Sciences/National Research Council Panel on Risk Assessment.

JOHN J. COSTOLNICK graduated from Northwestern University with an M.S. in chemical engineering and is a registered professional engineer. He retired as vice president of engineering at Exxon Chemical Company, where he worked for more than 35 years in positions of increasing responsibility, from manufacturing manager and plant manager to vice president for agricultural chemicals and vice president for basic chemical technology. Mr. Costolnick's areas of expertise are chemical operations and manufacturing.

FRANK P. CRIMI is a part-time consultant and retired vice president of Lockheed Martin Advanced Environmental Systems Company. He has a B.S. in mechanical engineering from Ohio University and has done graduate studies in mechanical engineering at Union College in Schenectady, New York. Mr. Crimi was appointed to the National Research Council Committee on Decontamination and Decommissioning of Uranium Enrichment Facilities and has firsthand knowledge and experience with radioactive and hazardous-waste treatment and disposal technologies.

J. ROBERT GIBSON is the assistant director of the Haskell Laboratory, E.I. du Pont de Nemours and Company, and an adjunct associate professor of marine studies at the University of Delaware. Since receiving his Ph.D. in physiology from Mississippi State University, Dr. Gibson has specialized in toxicology. He is certified by the American Board of Toxicology and has written numerous publications.

MICHAEL R. GREENBERG is a professor in the Department of Urban Studies and Community Health at Rutgers, The State University of New Jersey, and an adjunct professor of environmental and community medicine at the Robert Wood Johnson Medical School. His principal research and teaching interests include urbanization, industrialization, and environmental health policy. Dr. Greenberg holds a B.A. in mathematics and history, an M.A. in urban geography, and a Ph.D. in environmental and medical geography.

DEBORAH L. GRUBBE graduated from Purdue University with a B.S. in chemical engineering and received a Winston Churchill Fellowship to attend Cambridge University in England, where she received a Certificate of Postgraduate Study in chemical engineering. She is a registered professional engineer and engineer of record for DuPont, where she is currently corporate director for safety and health. Previously, she was operations and engineering director for DuPont Nonwovens, where she was responsible for manufacturing, engineering, safety, environmental systems, and information systems. She is a board member of the American Institute of Chemical Engineers Engineering and Construction Contracting Division and has led several committees of the Construction Industry Institute. Her areas of expertise are safety, chemical manufacturing technology, and project management and execution.

DAVID A. HOECKE, who graduated from Cooper Union with a B.S.M.E., is currently president and chief executive officer of Enercon Systems, Inc. His expertise is in the fields of waste combustion, pyrolysis, heat transfer, and gas cleaning. In 1960, he began working for Midland-Ross Corporation as a project engineer, becoming its chief engineer for incineration by 1972. At that time, he founded his own company, where he has been responsible for the design and construction of numerous combustion systems, including solid waste incinerators, thermal oxidizers, heat recovery systems, and gas-to-air heat exchangers.

DAVID H. JOHNSON graduated from the Massachusetts Institute of Technology with an Sc.D. in nuclear engineering. Currently senior vice president and chief scientist of EQE International, Inc., Dr. Johnson has

more than 20 years of experience in risk-based analysis for industry and government applications. His area of expertise is probabilistic risk assessments, including probabilistic modeling and investigation of the impacts of industrial projects.

CHARLES E. KOLB is president and chief executive officer of Aerodyne Research, Inc. Since 1971, his principal research interests at Aerodyne have included atmospheric and environmental chemistry, combustion chemistry, materials chemistry, and the chemical physics of rocket and aircraft exhaust plumes. He has served on several National Aeronautics and Space Administration panels dealing with atmospheric chemistry and global change, as well as on five National Research Council committees and boards dealing with environmental issues. He served as vice chair of the Stockpile Committee from mid-1997 to mid-2000. From 1996 to 1999, he was atmospheric sciences editor for *Geophysical Research Letters.* In 1997, he received the Award for Creative Advances in Environmental Science and Technology from the American Chemical Society.

GARY L. LAGE is the founding principal of ToxiLogics, Inc., where he is responsible for incorporating current data on the toxicology of chemicals and modern risk assessment into scientific decisions. For 20 years, he was an educator at the University of Kansas, the University of Wisconsin, and the Philadelphia College of Pharmacy and Science, where he taught pharmacology and toxicology. Dr. Lage was project director, vice president, and practice leader for human health practice at the Roy F. Weston Company for four years and a principal in the human health practice area with ENVIRON Corporation. He is a diplomate of the American Board of Toxicology and has a Ph.D. in pharmacology from the University of Iowa.

JAMES F. MATHIS, a member of the National Academy of Engineering, graduated from the University of Wisconsin with a Ph.D. in chemical engineering. Dr. Mathis was vice president of science and technology for Exxon Corporation, where he was responsible for worldwide research and development programs, and was chair of the New Jersey Commission on Science and Technology until his retirement in 1997. Dr. Mathis's expertise is in research and development and chemical engineering.

FREDERICK G. POHLAND, a member of the National Academy of Engineering, graduated from Purdue University with a Ph.D. in environmental engineering and is currently professor and Edward R. Weidlein Chair of Environmental Engineering at the University of Pittsburgh, as well as director of the Engineering Center for Environment and Energy and codirector of the Groundwater Remediation Technologies Analysis Center. He is a registered professional engineer and a diplomate environmental engineer and has taught and written extensively on solid and hazardous waste management, environmental impact assessment, and innovative technologies for waste minimization, treatment, and environmental remediation. Dr. Pohland has expertise in minimizing the impacts of hazardous waste on workers, the public, and the environment.

ROBERT B. PUYEAR graduated from Missouri School of Mines and Metallurgy with a B.S. in chemical engineering and from Purdue University with an M.S. in industrial administration. He is currently a consultant specializing in corrosion prevention and control, failure analysis, and materials selection. Mr. Puyear worked for Union Carbide for 16 years developing high-performance materials for chemical and aerospace applications and for Monsanto for 21 years as a corrosion specialist, where he managed the Mechanical and Materials Engineering Section. He is an expert in materials engineering and in the evaluation of materials of construction.

CHARLES F. REINHARDT, who has an M.D. from Indiana University School of Medicine and an M.Sc. in occupational medicine from Ohio State University School of Medicine, retired after more than 30 years with the DuPont Company, where he was a physiologist, then chief of the physiology section, and then research manager for environmental sciences. In 1971 he became assistant director of the laboratory and in 1976 was named its director, a position he held until his retirement in 1996. Dr. Reinhardt has served on numerous National Research Council panels and committees, including the Committee on Toxicology. His areas of expertise are occupational medicine and toxicology.

KENNETH F. REINSCHMIDT, a member of the National Academy of Engineering and a graduate of

the Massachusetts Institute of Technology (MIT) with a Ph.D. in engineering, is currently a consultant specializing in management of engineering, design, and construction projects; project and technology risk analysis; and project simulation and modeling. For 21 years he worked at Stone & Webster, Inc., from which he retired as senior vice president in 1996. He also taught civil engineering at MIT for 10 years. Dr. Reinschmidt's expertise is in project design, development, and construction.

W. LEIGH SHORT earned his Ph.D. in chemical engineering from the University of Michigan. He recently retired as a principal and vice president of URS Greiner Woodward-Clyde, where he was responsible for management and business development associated with the company's hazardous waste services in Wayne, New Jersey. Dr. Short has expertise in air pollution, chemical process engineering, hazardous waste services, feasibility studies, site remediation, and project management. He has taught courses in control technologies, both to graduate students and as a part of the Environmental Protection Agency's (EPA's) national training programs. He has also served as chairman of the EPA's NO_x Control Technology Review Panel.

JEFFREY I. STEINFELD graduated from the Massachusetts Institute of Technology with a B.S. in chemistry and from Harvard University with a Ph.D. in physical chemistry and is currently a professor of chemistry at MIT, where he has taught for almost 35 years. Dr. Steinfeld's expertise is in high-sensitivity monitoring techniques, pollution prevention, and environmental research and education, as well as in bringing scientific knowledge into environmental decision making via stakeholder involvement.

CHADWICK A. TOLMAN received his Ph.D. in physical chemistry from the University of California at Berkeley and is currently a program officer in the organic and macromolecular chemistry program in the Division of Chemistry of the National Science Foundation. He has extensive experience and expertise in chemistry and chemical process development. Dr. Tolman spent 31 years in Central Research at the DuPont Experimental Station. His work has spanned a broad range of subjects, from hydrocarbon oxidation and organometallic chemistry to the destruction of toxic organic compounds in wastewater.

WILLIAM TUMAS graduated from Ithaca College with a B.A. in chemistry and earned his Ph.D. in organic chemistry from Stanford University. After conducting postdoctoral research in organometallic chemistry at the California Institute of Technology as a National Institutes of Health and Chaim Weizman Postdoctoral Fellow, he worked for six years at DuPont Central Research and Development. Since 1993, Dr. Tumas has been at Los Alamos National Laboratory, where he is currently group leader of the Actinide, Catalysis, and Separations Chemistry Group in the Chemistry Division. His experience with the National Research Council includes service as a member of the Panel on Review and Evaluation of Alternative Chemical Demilitarization Technologies (1995–1996). His research interests include catalysis, supercritical fluids, environmental chemistry, and waste treatment technology assessment.