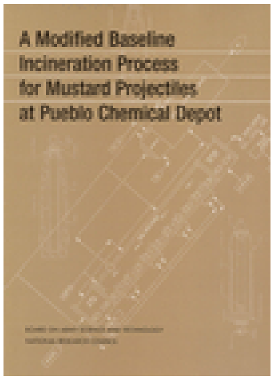

A Modified Baseline Incineration Process for Mustard Projectiles at Pueblo Chemical Depot

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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A MODIFIED BASELINE INCINERATION PROCESS FOR MUSTARD PROJECTILES AT PUEBLO CHEMICAL DEPOT

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

Board on Army Science and Technology
Division on Engineering and Physical Sciences
National Research Council

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Preface

The United States has maintained a stockpile of chemical warfare agents and munitions since World War I. In 1985, Public Law 99-145 mandated the expeditious destruction of M55 rockets containing chemical agents because of the chance they might self-ignite. The program was soon expanded into the Army's Chemical Stockpile Disposal Program (CSDP), which was given the mission of disposing of the entire 31,496 tons of nerve and mustard agents in a chemical stockpile dispersed among nine storage sites, eight in the continental United States and one on Johnston Island (part of Johnston Atoll) in the Pacific Ocean southwest of Hawaii. The United States is a signatory to the Chemical Weapons Convention treaty, which requires that the entire stockpile be destroyed by April 29, 2007.

The Army leadership has sought outside, unbiased advice on how best to dispose of the stockpile. In 1987, at the request of the Under Secretary of the Army, the National Research Council (NRC) established the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee) to provide scientific and technical advice and counsel on the CSDP. The committee has since produced 25 full-length and letter reports covering the evolution of the CSDP from the design and construction of the first incineration-based chemical agent disposal facility on Johnston Island in 1990 to the present. The stockpile at Johnston Island has now been completely eliminated, and the facility there is entering its closure phase. A second incineration-based facility has been operating for more than four and one-half years at Tooele, Utah, adjacent to the largest stockpile site. Similar facilities are being constructed at Anniston, Alabama; Pine Bluff, Arkansas; and Umatilla, Oregon. Although details differ at the five sites, the basic technology is the same (the baseline incineration system). At two other sites—Aberdeen, Maryland, and Newport, Indiana—alternative technologies to incineration are being implemented. Facilities for the final two sites—Pueblo, Colorado, and Blue Grass, Kentucky—are in the technology selection process.

This report is concerned with the technology selection for the Pueblo site, where only munitions containing mustard agent are stored. The report assesses a modified baseline process, a slightly simplified version of the baseline incineration system that was used to dispose of mustard munitions on Johnston Island. A second NRC committee is reviewing two neutralization-based technologies for possible use at Pueblo. The evaluation in this report is intended to assist authorities making the selection. It should also help the public and other non-Army stakeholders understand the modified baseline process and make sound judgments about it.

The committee is grateful for the considerable assistance of the Office of the Program Manager for Chemical Demilitarization and its contractors, which provided a great deal of useful information. The committee also greatly appreciates the assistance and contributions of NRC staff members Donald L. Siebenaler, Harrison T. Pannella, Daniel E.J. Talmage, Jr., and Carol R. Arenberg.

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Army Chemical Stockpile Disposal Program

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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:

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William R. Rhyne, H&R Technical Associates, Inc.

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 Hyla S. Napadensky (NAE), Napadensky Energetics, Inc. (retired), appointed by the NRC's Report Review Committee, 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.

Contents

EXECUTIVE SUMMARY 1

1 INTRODUCTION 6
  Background, 6
  National Research Council Involvement, 7
  Statement of Task, 7

2 EXPERIENCE AT JACADS WITH MUSTARD MUNITIONS 8
  Baseline Incineration System, 8
  Improved Processing of HD Munitions, 8
    Comparison of the 1992 and 1999 Trial Burn Results, 9
    Processing of 4.2-Inch HD Mortar Shells Through the MPF, 10
    Observations Based on HD Operations at JACADS, 10
  Findings and Recommendations, 12

3 THE MODIFIED BASELINE PROCESS 14
  Introduction, 14
  Description of the Modified Baseline Process, 14
    Transport of Munitions, 14
    Removal of Energetics, 14
    Energetics Disposal, 16
    Decontamination of Energetics, 17
    Freezing of Projectiles That Contain Agent, 17
    Opening of Munitions to Access Agent, 18
    Processing of Agent-Containing Munitions in the Metal Parts Furnace, 18
    Treatment of the Off-Gas from the Metal Parts Furnace, 19
    Handling of Brine Generated in the Quench Tower, 20
    Handling of Secondary Wastes, 20
    Monitoring of Agent and Other Pollutants, 21
    Infrastructure, 21
    Overall Throughput, 21
    Closure of the Facility, 22
  Critical Decisions for PMCD and Pueblo, 23
  Preproject Planning for a Modified Baseline Process, 23

4 RISK, SAFETY, AND STAKEHOLDER ISSUES 26
  Safety and Risk Considerations, 26
    Phase 1 QRA for a Baseline System at Pueblo, 26
    Other Risk Assessments, 27
  Worker Safety and Training, 28
  Stakeholder Contacts, 28
    Pueblo Chemical Depot, 28
    Emergency Management Plans, 29
    Colorado Department of Public Health and Environment and the Working Integrated Project Team Process, 29
    Citizens Advisory Commission, 30
    Evaluation of Pueblo Stakeholder Relations, 30

5 FINDINGS AND RECOMMENDATIONS 32

REFERENCES 36

APPENDIXES

A Description of Pueblo Chemical Depot Stockpile 41

B Reports by the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee) 44

C Biographical Sketches of Committee Members 46

List of Figures and Tables

FIGURES

3-1 Pueblo modified baseline process, 16

A-1 105-mm howitzer projectile, 42
A-2 155-mm howitzer projectile, 42
A-3 4.2-inch mortar cartridge, 43

TABLES

2-1 Summary of 1992 Trial Burn Tests for the Treatment of HD Ton Containers in the MPF at JACADS, 9
2-2 Metal Emissions in 1992 Trial Burn Tests at JACADS on HD Ton Containers in the MPF, 10
2-3 Number of HD Items Destroyed at JACADS, 10
2-4 Results of the 1999 Trial Burn of Mustard-containing Projectiles at JACADS, 11
2-5 Comparison of Limits from the JACADS RCRA Permit and Results of 1992 and 1999 Trial Burns, 11
2-6 Comparison of Selected Emissions (including those exceeding permit limits) for JACADS Trial Burns, 12

3-1 Comparison of Major Features of the Baseline Incineration System and the Modified Baseline Process, 15
3-2 Summary of Materials to Be Processed in a Four-zone MPF at Pueblo, 19
3-3 MPF Design Throughput Rates for Processing Munitions, 22

4-1 Summary of Results of Phase 1 QRAs for Baseline Incineration Systems at Several Sites, 27

A-1 Pueblo Chemical Depot Munitions, 41

Acronyms

ACAMS	automatic continuous air monitoring system
ACWA	Assembled Chemical Weapons Assessment
BRA	brine reduction area
CAC	Citizens Advisory Commission
CDTF	Chemical Demilitarization Training Facility
CHB	container handling building
CII	Construction Industry Institute
CSDP	Chemical Stockpile Disposal Program
CSEPP	Chemical Stockpile Emergency Preparedness Program
CWC	Chemical Weapons Convention
DAAMS	depot area air monitoring system
DFS	deactivation furnace system
DoD	U.S. Department of Defense
DPE	demilitarization protective ensemble
DPHE	Department of Public Health and Environment (Colorado)
DRE	destruction and removal efficiency
ECR	explosive containment room
EDS	explosive destruction system
EIS	environmental impact statement
EMC	emergency management coordinator
EPA	Environmental Protection Agency
GB	a nerve agent
HD	distilled mustard: bis(2-chloroethyl)sulfide
HEPA	high-efficiency particulate air
HRA	health risk assessment
HT	vesicant mixture: 60 percent bis(2-chloroethyl)sulfide and 40 percent bis[2(2chloroethylthio)ethyl] ether
JACADS	Johnston Atoll Chemical Agent Disposal System
LIC	liquid incinerator
MACT	maximum achievable control technology
MAV	modified ammunition van
MDB	munitions demilitarization building
MDM	multipurpose demilitarization machine
MPF	metal parts furnace
NEPA	National Environmental Policy Act
NOI	notice of intent
NRC	National Research Council
OMB	Office of Management and Budget
ONC	on-site container
OVT	operational verification testing
PAS	pollution abatement system
PCD	Pueblo Chemical Depot
PFS	PAS filter system
PIC	product of incomplete combustion
PMACWA	Program Manager for Assembled Chemical Weapons Assessment
PMCD	Program Manager for Chemical Demilitarization
PMD	projectile/mortar disassembly
PUCDF	Pueblo Chemical Agent Disposal Facility
QRA	quantitative risk assessment
RCRA	Resource Conservation and Recovery Act
SAIC	Science Applications International Corporation
SDS	spent decontamination solution
TOCDF	Tooele Chemical Agent Disposal Facility
TSDF	treatment, storage, and disposal facility

VX	a nerve agent
WIP	work in progress
WIPT	working integrated project team
3X	The 3X decontamination level refers to solids decontaminated to the point that the agent concentration in the headspace above the encapsulated solid does not exceed the health-based, eight-hour, time-weighted average limit for worker exposure. The limit for HD is 3.0 μg per cubic meter of air. Materials classified as 3X may be handled by qualified plant workers using appropriate procedures but may not be released to the environment or sold for general public reuse. In specific cases in which approval has been granted, a 3X material may be shipped to an approved hazardous waste treatment facility for disposal in a landfill or for further treatment.
5X	The use of 5X indicates that an item has been decontaminated completely of the indicated agent and may be released for general use or sold to the general public in accordance with all applicable federal, state, and local regulations. An item is decontaminated completely when the item has been subjected to procedures that are known to completely degrade the agent molecule, or when analyses, submitted through Army channels for approval by the Department of Defense Explosives Safety Board, have shown that the total quantity of agent is less than the minimal health effects dosage as determined by the Surgeon General. A 5X condition must be certified by the commander or designated representative. One approved method is heating the item to 538°C (1,000°F) for 15 minutes. This is considered sufficient to destroy chemical agent molecules.

Executive Summary

The Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program believes that a modified baseline process, derived from the baseline incineration system, is a workable concept for destroying the chemical stockpile at Pueblo Chemical Depot. Provided the many challenges described throughout this report can be successfully overcome in a timely manner, the committee believes that the proposed modified baseline process can be developed into a facility design that will meet the criteria set forth in Public Law 105-261 governing the selection of a technology for Pueblo. The modified baseline process should be as safe, rapid, and effective as the baseline incineration system in completing the destruction of the Pueblo stockpile. Under optimal developmental circumstances, it may prove even more efficacious than the baseline system. Whether destruction of the stockpile can be accomplished with either the baseline or the modified baseline process by April 29, 2007, the deadline set by the Chemical Weapons Convention (CWC), is uncertain.

The challenges to implementing a modified baseline process are both technical and nontechnical. The committee believes that if the Army acts promptly, the necessary technical developments could be completed and demonstrated. Administrative challenges, which involve obtaining regulatory approval for various system options, also appear to be surmountable. All of the challenges are fully discussed in the report.

General findings and recommendations are provided at the end of this Executive Summary. Specific findings and recommendations are presented throughout the report and are compiled in Chapter 5.

BACKGROUND

The Army, through the Program Manager for Chemical Demilitarization (PMCD), is responsible for destroying the U.S. stockpile of chemical munitions at nine storage sites. The portion of the stockpile at the Pueblo Chemical Depot in Colorado comprises 780,078 projectiles containing a total of 2,611 tons of mustard agent, the second largest number of munitions and the third largest amount of mustard agent stored at any site in the continental United States. The purpose of this report is to present an evaluation of one of the four technologies being considered for the destruction of the chemical munitions stored at Pueblo. This evaluation was conducted by the National Research Council (NRC) Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee).

The technology evaluated in this report is called the *modified baseline process* (a simplified version of the Army's baseline incineration system for the destruction of agent and energetics and the processing of secondary wastes associated with the chemical agents and munitions). Other technologies under consideration for the Pueblo site are the baseline incineration system and two nonincineration technologies. The latter two are the subject of another report by the NRC Committee on Review and Evaluation of Alternative Technologies for Demilitarization of Assembled Chemical Weapons: Phase II (ACW II Committee).

The modified baseline process proposed for the Pueblo site was derived from lessons learned during the disposal operations for mustard munitions at the first baseline incineration system facility, the Johnston Atoll Chemical Agent Disposal System (JACADS) and during general agent operations at a second baseline facility in Utah, the Tooele Chemical Agent Disposal Facility (TOCDF). Similar baseline systems are being installed at three other sites located in Alabama, Arkansas, and Oregon.

The neutralization-based technologies under consideration for the Pueblo site are being evaluated as part of the Assembled Chemical Weapons Assessment (ACWA) program through a separate Department of Defense (DoD) organization, the office of the Program Manager for Assembled Chemical Weapons Assessment. The ACWA program is assessing the two alternative technologies previously identified. Hydrolysis followed by supercritical water oxidation is planned for the Newport, Indiana, site to destroy the bulk VX nerve agent stored there in ton containers. Hydrolysis followed by biodegradation is planned for the Aberdeen, Maryland, site, where bulk mustard agent is stored, also in ton containers.

The process to select a technology for the Pueblo Chemical Agent Disposal Facility (PUCDF) was defined in a notice of intent (NOI) published in the Federal Register on April 20, 2000. Environmental impact statements required by the National Environmental Policy Act will be developed for all the candidate technologies. The final choice will be made by the DoD from the technologies certified to be as safe and cost efficient as the baseline incineration system, as well as capable of completing destruction of the Pueblo stockpile either by the CWC treaty deadline (April 29, 2007) or the date that would be achievable by the baseline system, whichever is later. The decision tentatively will be made in early fiscal year 2002.

EXPERIENCE AT JACADS WITH MUSTARD MUNITIONS

A large number of mustard projectiles of the type stored at Pueblo were successfully processed in the baseline incineration system at JACADS, although a number of operational problems were encountered. The lessons learned while solving these problems were incorporated in the modified baseline process for Pueblo. In the baseline system, following removal of energetic materials by the projectile/mortar disassembly machine in an explosive containment room, projectiles are drained of liquid agent by the multipurpose demilitarization machine (MDM); the drained agent is then sent separately to a liquid incinerator, where it is thermally oxidized. However, in the projectiles at JACADS, a solid "heel" of gelled mustard agent almost always remained, often as much as 40 to 50 percent of the original agent charge. Because the operating permit for the metal parts furnace (MPF) under the Resource Conservation and Recovery Act (RCRA) was based on processing no more than a 5 percent heel, the number of rounds per processing tray had to be restricted. The MPF production rate was reduced accordingly.

Moreover, liquid mustard agent often foamed up and overflowed the opened projectile casings, contaminating the MDM and the surrounding area. The MDM then had to be shut down and decontaminated with a neutralizing solution, after which it had to be cleaned and the corrosive effects of agent overflow and decontamination solution repaired.

JACADS personnel developed some imaginative solutions to the problems of foaming liquid agent and gelled agent heels. First, after receiving permission from the Environmental Protection Agency in 1999, JACADS conducted trial burns in which trays of 96 opened but undrained mustard projectiles were processed through the MPF. Although the mustard was successfully destroyed, stack emissions of mercury and cadmium were higher than the JACADS trial burn permit requirements. If these emissions could be lowered by high-efficiency particulate air (HEPA) and carbon filtration in a modified baseline design, all of the agent and the metal shells could be put through an MPF, which would eliminate the need for a liquid incinerator. Second, to minimize the frothing problem, a number of munitions were frozen before the agent cavities were opened to the atmosphere. Freezing had the disadvantage of adding another processing step, but is expected to reduce the downtime for maintenance. Processing frozen projectiles in the MPF was not actually tested at JACADS, because the few munitions that were opened in a frozen state had thawed by the time they reached the MPF.

Many of the secondary waste materials at JACADS were stored until the end of operations, at which time they were to be fed either to the MPF or the deactivation furnace system (DFS) or disposed of off site. Secondary wastes, such as demilitarization protective ensemble (DPE) suits, dunnage, and spent carbon media from air treatment filters for building exhaust, were tested in the MPF. Some secondary wastes were reportedly destroyed effectively, although the committee did not receive detailed confirming data. Brine produced as a by-product of the neutralization of acidic off-gases with caustic was shipped from Johnston Island for off-site disposal. Another secondary waste, spent decontamination solution, was charged to the afterburner of the liquid incinerator during ongoing operations.

After reviewing the lessons learned at JACADS, the committee judged them to be a valid basis for defining design improvements for a modified baseline process at Pueblo, including initiation of planning for closure during the facility design stage.

MODIFIED BASELINE PROCESS

The modified baseline process, discussed in some detail in this report, is a disposal option that can potentially destroy the Pueblo stockpile more rapidly than the baseline system. The main difference between the modified baseline process and the baseline incineration system is that fewer furnaces will be used—in fact, only one furnace is included in the most basic conceptualization of the modified process. Instead of the heavy on-site containers used at TOCDF to transport munitions from the storage igloos to the unloading dock of a two-story munitions demilitarization building (MDB), the proposed design calls for using modified ammunition vans at Pueblo to transport munitions to a single-story MDB. Energetics (propellant, fuzes, bursters) will be removed from the munitions using projectile/mortar disassembly machines. If possible, uncontaminated energetics will be sent off site to a treatment, storage, and disposal facility. If this is not allowed, a separate DFS may have to be added to process them.

If agent has penetrated the outside wall of the munition itself or the burster cavity, the munition is called a "leaker."

Among 94,000 mustard rounds at JACADS, 81 leakers were found, suggesting that the number of leakers at Pueblo may also be small. Leakers have been and will be overpacked in sealed containers and subsequently will be destroyed, most likely in the metal parts furnace.

Munitions, with their energetics removed, will then be moved by conveyer into freezers, where the contained agent will be frozen. Specialized machines (to be developed) will then drill a hole into, cut, or punch the projectiles to access the agent. The frozen, opened munitions will be placed in trays that will be conveyed through a four-zone MPF, in which the agent will be thermally oxidized to a destruction and removal efficiency (DRE) of 99.9999 percent. Decontaminated (5X)[1] metal shells will be shipped off site for disposal as scrap metal. Acidic gases from the MPF afterburner will be sent through a pollution abatement system (PAS), where the acids will be neutralized with caustic solution in a scrubber. Any brine produced will be shipped off site if possible. The gases (and some remaining particulate matter) will be cooled and dehumidified in another scrubber with a demister, reheated with gas-fired heaters, and drawn by two induced-draft fans in series through the PAS filter system (PFS) that includes HEPA filters both upstream and downstream of carbon filters.

The modified MPF is expected to have a higher throughput rate than the MPF in the baseline system if the proposed HEPA filters in the PFS prove adequate to meet emission limits at higher throughput rates. Agent will not be removed from the munitions (as it is in the baseline incineration system), and the MPF in the modified baseline process has four zones (instead of the three-zone MPF in the baseline system) in order to process the mustard agent in the munitions more productively.

The PFS planned for the modified process (and for some baseline systems) is expected to provide additional protection against the release of metals, metallic compounds, and undesirable organics to the atmosphere. However, PFS tests have not yet been conducted at the Anniston, Pine Bluff, and Umatilla baseline facilities, all of which are nearing the systemization phase. Therefore, the capability to meet the Pueblo air emissions limits has not been demonstrated. Mechanical and operational process improvements based on lessons learned at these sites could be incorporated into both the MPF and PAS/PFS designs for the modified baseline process at Pueblo.

Procedures for monitoring agent and handling secondary waste are similar in the baseline system and the modified baseline process. Careful measurements of agent levels will be taken at many locations in the MDB and around the perimeter of the PUCDF. Secondary wastes will be burned in the MPF or shipped off site. Because only one or at most two furnaces would be necessary for the modified baseline process (instead of the three to five in a baseline incineration system—one or more separate furnaces for liquid agent, metal parts, energetic materials, and dunnage or packing materials), the modified baseline process will probably be simpler. Until additional analyses associated with the Phase 1 quantitative risk assessment and the health risk assessment (HRA) are completed, there are insufficient data to quantify the safety of the modified baseline process relative to the baseline system.

EVALUATION OF THE MODIFIED BASELINE PROCESS

The Stockpile Committee was asked to evaluate the modified baseline process in time for the environmental impact assessment proceedings during the summer of 2001. It therefore based its evaluation on data and information received through March 2001. When this report was prepared for publication, the modified baseline process was still undergoing design and development changes. Under these conditions, the committee tried to present its findings and recommendations in terms that will be useful to the Army as design and development proceeds. Some alternatives for a final process design for Pueblo are also offered.

Overall, the modified baseline process concept is likely to be a workable means of destroying the assembled chemical munitions stockpile at Pueblo. As previously noted, the modified baseline process is based on the extensive lessons learned from the processing of mustard agent munitions at JACADS. Even so, some development work will be necessary. The committee believes that with rigorous planning and execution these tasks can be accomplished.

Whether all aspects of the new process, from design through destruction of the Pueblo stockpile, can be accomplished in time to meet the CWC deadline of April 29, 2007, is not certain, because obtaining permits and proving the modified baseline process may be more difficult and time consuming than anticipated by the Army. The introduction of frozen agent into the MPF is an element of the modified process that will either have to be tested and developed further or eliminated. In addition, the equipment for accessing agent in frozen munitions and verifying that it has been accessed will have to be developed and proven.

In the following sections, the findings and recommendations that appear throughout the report are summarized.

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[1] The use of 5X indicates that an item has been decontaminated completely of the indicated agent and may be released for general use or sold to the general public in accordance with all applicable federal, state, and local regulations. An item is decontaminated completely when it has been subjected to procedures that are known to completely degrade the agent molecule, or when analyses, submitted through Army channels for approval by the Department of Defense Explosives Safety Board, have shown that the total quantity of agent is less than the minimal health effects dosage as determined by the Surgeon General. A 5X condition must be certified by the commander or designated representative. One approved method is heating the item to 538ºC (1,000ºF) for 15 minutes. This is considered sufficient to destroy chemical agent molecules.

Summary of Findings

More than 95,000 mustard projectiles were successfully processed in the MPF at JACADS. A 1999 trial burn of the JACADS MPF demonstrated a DRE of 99.9999 percent for agent. This suggests that the modified baseline process, in which munitions are charged to the MPF, can destroy the mustard agent munitions at Pueblo Chemical Depot if the MPF can be shown to handle frozen projectiles safely and effectively. The MPF is a crucial component of the modified baseline process, and its design and size will be critical; it has been expanded from the three-zone configuration used at JACADS to a four-zone configuration for Pueblo.

The modified baseline process possesses many attributes identical to those of the baseline incineration system used at JACADS and TOCDF. Several features have been modified substantially, however, to address the problem of foaming encountered at JACADS when mustard munitions were opened prior to processing. In the modified baseline process, munitions will be frozen before they are drilled, cut, or punched open. In a test at JACADS, only a small number of partially frozen munitions (and no fully frozen munitions) were put through the MPF. Therefore, data on the destruction in the MPF of agent in frozen rounds will be essential. However, thawed munitions could be processed, as at JACADS, without significant additional data. Whether data can be obtained (and regulatory approval completed) without affecting the schedule is an open question. The machinery for opening frozen rounds would still have to be developed, pass performance tests, and be manufactured.

In the 1999 trial burn with mustard munitions at JACADS, emissions of mercury and cadmium exceeded regulatory standards. Newer facilities are equipped with a PFS, which would also be used at Pueblo. This system may be sufficient to bring the emissions to regulatory levels. Tests of such a system are planned in the near future.

Monitoring systems for agent and stack emissions used at baseline system facilities, in conjunction with a third (standby) automatic continuous air monitoring system (ACAMS) in the area of the MPF, appear to be adaptable for use with a modified baseline process at Pueblo. By the time Pueblo operations begin, developments in the real-time monitoring of environmentally sensitive metals, dioxins, and products of incomplete combustion may make more frequent monitoring of these substances possible. If not, the Army could conduct stack tests at suitable intervals to provide evidence to the surrounding communities that the modified baseline process is working properly.

Treatment of secondary wastes at Pueblo will be an important issue. Some secondary wastes (dunnage and DPE suits) were successfully processed through the MPF at JACADS. Although the same processing is planned in the modified baseline process, supporting data and information were not available to the committee. Spent decontamination solution was charged to a liquid incinerator afterburner at JACADS. There will be a similar afterburner for the MPF of the modified baseline process available for such use. Spent filter carbon may be micronized (ground into fine particles) and burned as planned at JACADS or shipped off site. Here again, a similar method of disposal may be employed at Pueblo.

The current plan for a modified baseline process at Pueblo calls for shipping agent-free energetics to off-site destruction facilities, and negotiations with regulatory agencies and outside disposal facilities are under way. If off-site shipment is not permitted, an on-site DFS will be used; if the decision to use a DFS is delayed, it could adversely affect the project schedule.

Problems with the closure of JACADS are proof of the importance of planning for closure at the beginning of any chemical agent disposal project. However, there is no evidence of planning for closure of the Pueblo facility.

In general, preproject planning is a key ingredient of successful large projects. OMB Circulars A-94 and A-11 provide guidance for the performance of government agencies on such projects, particularly with regard to schedules and risk analyses. Compliance with these circulars enhances the chances of keeping a project on schedule.

The Phase 1 quantitative risk assessment for Pueblo and several other stockpile sites with assembled chemical munitions completed several years ago showed that the stockpile at Pueblo presents risk to public health several orders of magnitude lower than any other site. This is because it contains only mustard agent, which is less volatile than other agents, and therefore would not be carried very far in the event of a fire or explosion. Nevertheless, the Army has undertaken several risk and safety assessments to meet the legislative requirement that the technology chosen for Pueblo be as safe as or safer than the baseline system. The committee believes that the incineration technologies under consideration will have very low risk and will meet reasonable interpretations of safety criteria, even if the actual risk numbers marginally exceed the baseline criteria.

Finally, the committee identified ways the Army and its contractors can communicate better with the stakeholders at Pueblo. Although the overall public involvement effort of the Program Manager for Chemical Demilitarization has improved, more can be done in this area.

Summary of Recommendations

The modified baseline process with a single four-zone MPF shows considerable promise and should be considered for destroying the Pueblo stockpile. Certain features of the process do require additional study, as recommended below.

Freezing may be an effective way to minimize the frothing that sometimes occurs when mustard projectiles are cut open; but in view of past experiences and alternative plans at other baseline system facilities, the Army should determine if this is the best approach. If freezing is determined to be the optimal approach, experimental data on processing frozen rounds through an MPF should be developed. The new machinery for opening frozen rounds and verifying that they are open should be thoroughly tested to ensure that the agent cavity will be opened consistently. The time required to acquire this information and to obtain regulatory approval for treating frozen rounds in the MPF could jeopardize the project schedule. The Army should take this possibility into account and make appropriate plans, including allowing the frozen rounds to thaw, thereby duplicating the limited experience at JACADS.

The Army should develop a process and schedule, including uncertainties in the permitting process, to determine the latest point in time when a decision can be made either to ship energetics off site or to dispose of them in a DFS and still meet the CWC treaty deadline. Tests should be undertaken to verify that stack emissions of heavy metals would be limited to acceptable levels by whatever technology is selected. The Army should also evaluate state-of-the-art tools for the continuous monitoring of emissions of metals, dioxins, and the products of incomplete combustion and, if practicable, install them at Pueblo.

The Army should review the data from JACADS on the processing of secondary wastes in the MPF and obtain more data, if necessary, to determine if the MPF in a modified baseline process can treat them satisfactorily. Plans for treating all secondary wastes, including DPE suits, dunnage, spent decontamination solution, and spent carbon, should be completed.

The Army should initiate closure planning for Pueblo as soon as practicable.

For preproject and project planning, the Army should follow the requirements of OMB Circulars A-94 and A-11 for capital projects and develop detailed plans.

Necessary risk studies should be completed as quickly as possible. Before the HRA is completed, the Army should work with the Pueblo stakeholders to decide how the risk of a modified baseline process facility compares with that of a baseline incineration system facility. This will require that the Army increase and improve its communications with stakeholders. Finally, the Army should make safety the number one objective in the construction, systemization, operation, and closure of the Pueblo Chemical Agent Disposal Facility.

1

Introduction

BACKGROUND

The United States is a signatory to the 1997 international Chemical Weapons Convention (CWC), which mandates the destruction of all chemical agent and munitions stockpiles by April 29, 2007. The Army has undertaken a program funded by the Congress to meet that deadline. Of the original 31,496 tons of chemical agents in the nine U.S. stockpiles, more than 7,000 tons, approximately 22 percent, have been destroyed in two chemical agent disposal facilities, the Johnston Atoll Chemical Agent Disposal System (JACADS) on Johnston Island (part of Johnston Atoll) southwest of Hawaii and the Tooele Chemical Agent Disposal Facility (TOCDF) in Utah.[1] These facilities and three similar facilities under construction in Anniston, Alabama; Pine Bluff, Arkansas; and Umatilla, Oregon, use or will use the baseline incineration system to process the stockpiles at those sites.

Neutralization-based technologies (alternatives to incineration) are being installed at the chemical stockpile site in Newport, Indiana, where bulk-only VX nerve agent is stored, and in Aberdeen, Maryland, where bulk-only mustard agent is stored. The selection of technologies for the last two sites, at Pueblo, Colorado, and Blue Grass, Kentucky, is under way.

In April 2000, the Army published a notice of intent (NOI) to prepare a site-specific environmental impact statement (EIS) for a facility to destroy the mustard agent and munitions stored at Pueblo Chemical Depot (PCD) in accordance with National Environmental Policy Act (NEPA) requirements. Four technology options are under consideration: the baseline incineration system, a modified baseline process, and the two neutralization-based[2] processes noted above. The NOI also listed the possibility of continued storage of the munitions.

The Army originally intended to use the baseline incineration system at Pueblo but later reconsidered. For various reasons, the choice of a technology has still not been formalized. This report was written in response to a request by the Army's Program Manager for Chemical Demilitarization (PMCD) that the National Research Council evaluate a proposed modified baseline process for the disposal of the stockpile of mustard agent munitions at PCD. The modified baseline process is a simplified, second-generation version of the baseline incineration system developed in response to lessons learned during the processing of mustard agent munitions at JACADS.

The Assembled Chemical Weapons Assessment (ACWA) Program was funded under Public Law 104-208 and subsequent congressional legislation to pursue the development of alternative technologies for the disposal of assembled chemical weapons. The Program Manager for Assembled Chemical Weapons Assessment (PMACWA), who is responsible for conducting research and development for the ACWA Program, reports to the Under Secretary of Defense for Acquisition, Technology, and Logistics, not to the Army. PMACWA published a second, separate NOI in April 2000 announcing its intent to prepare a programmatic EIS to cover the design, construction, and operation of one or more pilot test facilities for the ACWA technologies selected for implementation at any of the stockpile sites. Se-

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[1] JACADS completed the destruction of the 2,031 tons of chemical agent originally stockpiled on Johnston Island in November 2000. Since disposal operations began at TOCDF in August 1996, approximately 5,000 tons of the 13,616 tons stockpiled at the Tooele, Utah, site have been destroyed.

[2] The Army refers to the destruction of chemical agent by hydrolysis as chemical *neutralization*. The term is derived from the military definition of *neutralize*: to render something unusable or nonfunctional. Hydrolysis is a reaction of a target compound with water, often catalyzed by an acid or a base, in which a chemical bond is broken in the target and the components of water, OH^- and H^+, are inserted at the site of the bond cleavage. The technical definition of neutralization is a chemical reaction between an acid and a base to form a salt and water. Chemical agents are neither acids nor bases, however, so the use of the term neutralization is somewhat confusing. Nevertheless, in the literature on chemical demilitarization in aqueous systems, the terms *neutralization* and *hydrolysis* are used interchangeably.

lected technologies must meet the requirements specified in Public Law 105-261:

> . . . [for] an alternative technology for the destruction of lethal chemical munitions, other than incineration, that the Under Secretary—
> (A) certifies in writing to Congress is—
> (i) as safe and cost effective for disposing of assembled chemical munitions as is incineration of such munitions; and
> (ii) as capable of completing the destruction of such munitions on or before the later of the date by which incineration were used or the deadline date for completing the destruction of the munitions under the Chemical Weapons Convention; and . . .

Although the total tonnage of mustard agent contained in the munitions at Pueblo is not large (2,611 tons), the number of munitions (approximately 780,000 mortar shells and artillery projectiles) is the second largest stored at any of the eight continental U.S. stockpile sites. A description of the munitions in the Pueblo stockpile is provided in Appendix A.

NATIONAL RESEARCH COUNCIL INVOLVEMENT

The National Research Council (NRC) is assisting the Army in the selection of a technology for Pueblo with two committees: the standing Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee) and the Committee on Review and Evaluation of Alternative Technologies for the Demilitarization of Assembled Chemical Weapons: Phase II (ACW II Committee). This report was prepared by the Stockpile Committee, which has provided scientific and technical advice and counsel to the Army's Chemical Stockpile Disposal Program since 1987. The membership of the committee is periodically adjusted to provide the requisite expertise for each study.

The ACW II Committee advises the U.S. Department of Defense (DoD) on its ACWA Program. Since 1997, the ACW II Committee and its predecessor (the ACW I Committee) have followed the development of several alternative (to incineration) technologies for the demilitarization of assembled chemical weapons. In parallel with this modified baseline process report, the ACW II Committee is preparing a report to evaluate the two ACWA technologies being considered for Pueblo.

STATEMENT OF TASK

The statement of task for a study of the modified baseline process was agreed upon by the NRC and the PMCD:

> The Stockpile Committee should:
>
> - review documented lessons learned by the PMCD during baseline incineration system disposal operations for mustard projectiles conducted at the Johnston Atoll Chemical Disposal System (JACADS)
> - assess tailoring by the PMCD of the lessons learned at JACADS for disposal of the mustard projectiles located at the Pueblo Chemical Depot
> - monitor developments with respect to the NEPA [National Environmental Policy Act] EIS process for a chemical disposal facility at the Pueblo site that will consider not only a modified baseline incineration system but also the original baseline system and demonstrated ACWA technologies
> - receive briefings from PMCD project personnel, NEPA document preparers, and other stakeholder parties
> - conduct site visits as required
> - review and evaluate design information generated by the Army for preparing permit applications and complying with the NEPA process in terms of technical feasibility, preliminary safety evaluations, and environmental compliance
> - prepare a report for release

In keeping with its statement of task, the committee gathered and reviewed information from numerous sources. In June 2000, the committee was briefed in detail on munition-processing experiences at JACADS that led to the concept of a modified baseline process (personal communication from Gary W. McCloskey, PMCD JACADS Site Project Manager, June 22, 2000). In July and November 2000, PMCD and its contractors provided focused technology briefings to committee members on developments pertaining to the modified baseline process. Committee members also attended meetings in September and December 2000 at which PMCD presented technology reviews to industrial contractors interested in constructing or operating the Pueblo Chemical Agent Disposal Facility (PUCDF). Committee members visited PCD in October and December 2000 and met with PCD management, regulatory representatives, and emergency response personnel. During these visits, committee members also attended meetings of the Colorado Chemical Demilitarization Citizens Advisory Commission (CAC), which are open to the public. Finally, the committee received additional data and information at its regular committee meetings in June and October 2000 and January and March 2001.

Chapter 2 reviews the lessons learned at JACADS. Chapter 3 assesses the adoption of these lessons into the modified baseline process and evaluates the design information available at the time the report was prepared. Chapter 4 presents the results of stakeholder interactions, as well as safety and risk management considerations. Findings and recommendations are provided in each chapter and compiled in Chapter 5.

This evaluation represents the committee's understanding of the conceptual design of the modified baseline process based on information made available at the time the report was prepared. Because preliminary cost estimates and schedule information were not made available, the committee could not evaluate cost and schedule implications.

2

Experience at JACADS with Mustard Munitions

BASELINE INCINERATION SYSTEM

The baseline incineration system, for which JACADS provided the prototype, is thoroughly described in the 1994 NRC report *Recommendations for the Disposal of Chemical Agents and Munitions* (NRC, 1994). The baseline incineration system was designed to separate, process, prepare, and dispose of four agent and munitions waste streams: agent (liquid incinerator [LIC]), energetics (deactivation furnace system [DFS]-rotary kiln), contaminated metal components (metal parts furnace [MPF]), and packaging and other materials (dunnage furnace).

Neither JACADS nor TOCDF, the two baseline facilities that have processed both agent stored in bulk (ton) containers and chemical munitions, was built and operated exactly according to the original design. JACADS, the first baseline facility to become operational, was also the first to encounter unanticipated problems, the majority of which were solved in ways not envisioned in the original design of the system. For example, although a dunnage furnace at JACADS was included in the facility design, constructed, and had a successful trial burn, it has not been used in recent years.

Prior to full-scale JACADS operation, trial burns were conducted to confirm that the destruction and removal efficiency (DRE) for agents of all of the baseline system furnaces met the criteria of the Environmental Protection Agency (EPA). Because the processing of chemical agent and chemical munitions was unprecedented, and because the process failures could have catastrophic effects on personnel and the environment, Congress mandated that the Army conduct an operational verification test program to confirm that operations were safe before allowing construction of baseline facilities to begin in the continental United States (U.S. Army, 1992). Table 2-1 summarizes test conditions and results from the four 4-hour test runs conducted in August 1992 on ton containers in the MPF (U.S. Army, 1992). Table 2-2 shows the results of trial burns for metal emissions (U.S. Army, 1992).

As Table 2-1 shows, the treatment of the mustard agent (HD) resulted in stack concentrations, DRE, operating temperatures, carbon monoxide concentrations, stack particulate concentrations, and hydrogen chloride emissions that were all within required limits for all four test runs. At the time the trial burn report was prepared, no limits had been established for metals. However, the report notes that the measured concentrations were very close to the detection limits in all cases (U.S. Army, 1992). It is not clear whether the low concentrations were due to low metals content in the agent stream or to the effective removal of metals during processing.

Disposal campaigns for HD ton containers and three types of projectiles containing HD were completed at JACADS in mid-1999, at which time all mustard agent stored on Johnston Island had been destroyed. Table 2-3 shows the total number of HD items processed. There were no HT mustard-filled containers or munitions at JACADS. While HD and HT are very similar, and the results of their combustion could be expected to be much the same, the committee has no evidence of analysis or testing to this effect.

IMPROVED PROCESSING OF HD MUNITIONS

Multipurpose demilitarization machines (MDMs) are used in the baseline system to extract the press-fit burster well from the projectile body and drain agent from the munition. During the processing of a significant number of the HD projectiles at JACADS listed in Table 2-3, the agent foamed and overflowed the projectile casing when the burster casing was ruptured or removed (U.S. Army, 2000a). The MDM then had to be shut down and the mustard agent, which is corrosive, had to be decontaminated with a neutralizing solution; then the MDM had to be cleaned and repaired. Maintenance personnel, who performed this work in demilitarization protective ensemble (DPE) suits, thus generated large amounts of spent decontamination solution (SDS) and contaminated DPE suits. The additional maintenance reduced

TABLE 2-1 Summary of 1992 Trial Burn Tests for the Treatment of HD Ton Containers in the MPF at JACADS

Parameter	Units	Test Run 1	Test Run 2	Test Run 3	Test Run 4	Requirement
Average quantity of agent per container	lb	12.8	51.8	58.4	60.3	
HD evaporation rate (maximum)	lb/hr	54	114	111	105	≤146.2
Concentration of HD in stack	mg/m^3	ND[a]	ND	ND	ND	<0.03
DRE for HD	%	>99.9996	>99.9997	>99.9997	>99.9997	≥99.99
Operating temperature in primary chamber	°F					
First zone		1,408	1,425	1,418	1,457	1,450 ± 250[b]
Second zone		1,456	1,453	1,460	1,461	1,450 ± 250
Third zone		1,459	1,449	1,449	1,451	1,450 ± 250
Afterburner temperature	°F	2,003	2,003	2,003	1,998	2,000 + 250 or –100
Afterburner CO output (corrected to 7% O_2)	ppm	9.0	9.0	1.7	1.1	
(Average PAS one-hour rolling average)		13.0	12.7	2.0	2.1	≤100[c]
Particulate concentration in stack[d]	mg/dscm[e]					
Corrected to 7% O_2		10.92	2.68	3.13	0.89	≤180
Corrected to 12% O_2		13.35	3.29	3.79	1.03	
HCl emissions	lb/hr	ND[f]	0.0497	ND	ND	≤4
Stack gas flow[d]	acfm[g]	11,338	11,918	11,801	11,772	
	dscfm[h]	6,002	6,333	6,150	6,121	
Oxygen (Orsat)[d]	%	14.5	14.8	14.5	14.2	
Carbon dioxide (Orsat)[d]	%	4.6	4.3	4.5	4.9	

[a] ND = none detected. Detection limits were 0.0054, 0.0066, 0.0069, 0.0066 mg/m^3 for test runs 1, 2, 3, and 4, respectively.
[b] The permit requirement of 1,450±150°F was revised to 1,450±250°F by memorandum of understanding.
[c] 100 ppm is the hourly rolling average limit. The peak limit for five minutes is 200 ppm. Both corrected to 7% oxygen.
[d] Average of MMT (multimetals train) and M5AT (method 5 acid train) particulate results.
[e] Dry standard cubic meter.
[f] ND = none detected. Detection limits were 0.00326, 0.00277, 0.00328 lb/hr for test runs 1, 3, and 4, respectively.
[g] Actual cubic feet per minute.
[h] Dry standard cubic feet per minute.

Source: Adapted from U.S. Army, 1992.

processing rates, thus increasing overall facility costs. An innovative solution to the frothing problem was developed by freezing the agent in the projectile before opening the agent cavity. About 200 rounds were successfully processed in this manner (Tomanek, 2000a, 2000b).

During the processing of munitions at JACADS, operators also noted that a high percentage of HD-filled projectiles, especially 4.2-inch mortar rounds, did not conform to the design criteria of the baseline system, which specified that agent be in a liquid state and that 95 percent of the agent fill be removed. In fact, data showed that on average only 60 percent of the agent fill was removed by the MDMs (SAIC, 1998). Even at this reduced rate, plugging of the drain system and interruptions in processing occurred, and the removal rate had to be reduced to 50 percent to avoid plugging of the drain system (U.S. Army, 2000b). This resulted in a higher-than-expected agent load to the MPF for a significant number of projectiles. Because the RCRA permit was based on agent loading rather than on the number of projectiles processed, the processing rate was severely curtailed (EPA, 1998).

In the absence of experience with chemical agent disposal operations, the original permit issued by EPA for operating the MPF had set a feed rate based on the schedule established for accomplishing the JACADS disposal mission, rather than on the capacity of the MPF to destroy agent feeds to the required DRE. With EPA cooperation, a new trial burn was undertaken in 1999 to support a RCRA permit modification that would allow the processing of batches of 96 mortar projectiles, which had energetics and burster wells removed and were completely filled with agent, through the three zones of the MPF at JACADS. Table 2-4 shows the results of the 1999 trial burn, which confirmed that the MPF could process more agent than the 5 percent residual agent heel permit limit and, in fact, was capable of destroying completely filled projectiles in full compliance with RCRA requirements for agent DRE (U.S. Army, 1999b).

Comparison of the 1992 and 1999 Trial Burn Results

The principal differences between the 1992 and 1999 trial burns were the rates of agent loading and the types of containers processed. In 1992, agent was introduced to the MPF in a single ton container that had been punctured; in 1999, agent was introduced in a tray of 96 projectiles filled to

TABLE 2-2 Metal Emissions in 1992 Trial Burn Tests at JACADS on HD Ton Containers in the MPF

	Test Run			
	1	2	3	4
Sample volume (dscm)	1.25	1.39	1.34	1.33
Metal	Concentration[a] µg/dscm[b]			
Arsenic	0.8	18.4	ND[c]	1.6
Selenium	5.7	4.2	ND	ND
Chromium	1.5	2.3	2.6	2.6
Lead	ND	16.0	6.3	17.0
Barium	ND	ND	ND	8.2
Tin ND	ND	12.0	ND	
Phosphorus	97.0	43.0	81.0	84.0
Zinc	21.0	27.0	21.0	22.0
Boron	205.0	81.0	161.0	132.0
Manganese	0.2	8.6	409.0	2.1
Copper	ND	5.1	3.8	ND
Mercury	ND	6.4	4.7	2.0

[a] Values blank corrected using the field blank results.

[b] Micrograms per dry standard cubic meter.

[c] ND = none detected; detection limits listed below.

Run 1: 4.0 µg/dscm for lead and copper
8.0 µg/dscm for barium and tin
1.6 µg/dscm for mercury

Run 2: 7.2 µg/dscm for barium and tin

Run 3: 3.7 µg/dscm for arsenic and selenium
7.5 µg/dscm for barium

Run 4: 3.8 µg/dscm for selenium and copper
7.5 µg/dscm for tin

Source: Adapted from U.S. Army, 1992.

TABLE 2-3 Number of HD Items Destroyed at JACADS

Mustard (HD) Munition/Container	Quantity
155-mm projectiles	5,779
105-mm projectiles	45,154
4.2-inch mortar projectiles	43,660
Ton containers	68

Source: U.S. Army, 1999a.

capacity, with the agent cavity of each projectile punctured and open to the atmosphere inside the MPF. This increased the weight of HD processed from 60 lb to more than 500 lb. There were also differences in MPF operating temperatures and other parameters, such as the surface area for agent evaporation. In 1992, EPA required an operating temperature of 1,450°F±250°F. In four test runs, the actual measured temperatures ranged from 1,408°F to 1,461°F (U.S. Army, 1992). In 1999, EPA required a primary chamber "set point" temperature of 1,600°F with an allowable range of 1,425°F to 1,750°F. The multirun trial burn average temperature was 1,596°F (U.S. Army, 1999b). Table 2-5 is a comparison of limits from the 1998 JACADS RCRA permit and 1992 and 1999 trial burn data. Table 2-6 is a comparison of selected emissions, including those that exceeded permit limits.

The 1992 trial burn results did not violate existing air quality standards; however, standards for metals had not yet been established. Both cadmium and mercury emissions in the 1999 trial burn exceeded 1998 standards. The JACADS project manager ascribed the source of mercury in the emissions to spillage of mercury from manometers during the filling of the projectiles with agent, which probably was not a problem in the ton containers used in the 1992 trial burn (personal communication from Gary W. McCloskey, PMCD JACADS Site Project Manager, June 22, 2000). The source of the cadmium emissions is silver solder. Extensive sampling of the stack gases for organic compounds was also conducted. No emissions of dioxins, furans, polychlorinated biphenyls or any of the 138 other semivolatile organic compounds were detected. All emissions were well within RCRA permit levels (U.S. Army, 1999b). The DRE of agent was 99.9999 percent, well above the RCRA 99.99 percent target.

Processing of 4.2-Inch HD Mortar Shells Through the MPF

Despite the emissions of cadmium and mercury that exceeded current standards during the 1999 trial burn, EPA extended the JACADS operating permit for the MPF to allow incineration of punched but undrained (energetics and burster well removed) 4.2-inch mortar shells in trays of 96 rounds. The target temperature setting for Zone 1 of the MPF had to be lowered from 1,600°F to 1,475°F because of the larger quantity of agent being oxidized at peak loading (Webster, 2000). Additional modifications to process parameters were made to adjust for the disposal of SDS in the LIC afterburner and for the effects of processing secondary wastes.

Observations Based on HD Operations at JACADS

The modified baseline process for Pueblo that the committee examined was developed from successful operations of the baseline system at JACADS and lessons learned during the processing there of mustard-filled munitions. Solutions developed and tested at JACADS for problems encountered during the disposal of mustard-filled munitions were the basis for process modifications and are considered to be applicable to the PCD stockpile. The committee's principal observations from the JACADS experience are as follows:

TABLE 2-4 Results of the 1999 Trial Burn of Mustard-containing Projectiles at JACADS

Emissions Parameter	Permit Section Module V[a]	Permit Limit	MPF Results (four-run average)	Compliance Limit Met
Agent DRE	V.B.1	99.99%	>99.999999%	Yes
Particulate matter	V.B.3	180 mg/dscm[b]	3.8 mg/dscm[b]	Yes
Hydrogen chloride (HCl)	V.B.2	1.8 kg/hr	<0.003 kg/hr	Yes
Carbon monoxide (CO)	V.F.2.c	100 ppm[b]	14.1 ppm[b]	Yes
Agent HD concentration[c]	V.F.2.j	0.03 mg/m^3	<0.000150 mg/m^3 [c]	Yes

Trace Metals	EPA Permit Limits[d] (g/sec)	MPF Results (g/sec)	Compliance Limit Met
Antimony (Sb)	5.87 E-05	<4.68 E-07	Yes
Arsenic (As)	8.52 E-05	1.64 E-06	Yes
Barium (Ba)	6.14 E-05	<3.37 E-05	Yes
Beryllium (Be)	2.38 E-05	<3.33 E-07	Yes
Cadmium (Cd)	2.98 E-05	<4.02 E-05	No[e]
Chromium (total)	2.87 E-05	<1.54 E-06	Yes
Lead (Pb)	7.93 E-05	9.54 E-06	Yes
Mercury (Hg)	4.29 E-05	<2.25 E-04	No[e]
Silver (Ag)	1.91 E-05	<4.52 E-06	Yes
Thallium (Tl)	1.91 E-05	<1.48 E-07	Yes

[a] JACADS permit (July 1998), module V.

[b] Milligrams per dry standard cubic meter (dscm) corrected to 7 percent O_2 or parts per million by weight.

[c] Determined from analysis of special DRE Depot Area Air Monitoring System (DAAMS) sorbent tubes at Station 18 Common Stack.

[d] JACADS RCRA permit Table 5-12, “Maximum Allowable Stack Emissions Limits.”

[e] The analytical data in Table 2-4 are the averaged results from four different trial burns conducted in 1999. For both mercury and cadmium, in three of the four analyses, the levels were below the detection limit. However, in one case for each metal, the measured levels were above the detection limit and in excess of the MACT standard, which is probably the reason the EPA showed noncompliance.

Source: Adapted from U.S. Army, 1999b.

TABLE 2-5 Comparison of Limits from the JACADS RCRA Permit and Results of 1992 and 1999 Trial Burns

Emission Parameter	1998 Permit Limit	1992 Trial Burn	1999 Permit Level
Agent DRE	99.99%	99.9997%	>99.999999%
Particulate matter, corrected to 7% O_2	180 mg/dscm	4.41 mg/dscm	3.8 mg/dscm
Hydrogen chloride	1.8 kg/hr	0.03 kg/hr	<0.003 kg/hr
Carbon monoxide	100 ppm	7.45 ppm	14.1 ppm
Agent HD concentration	0.03 mg/m^3	None detected	<0.000150 mg/m^3

Source: U.S. Army, 1992, 1999b.

1. Although JACADS encountered numerous operational problems during processing, many of which were unanticipated in the baseline system design, the facility maintained a good safety record for agent processing and handling.
2. Munitions filled with HD drained more slowly and with more difficulty than expected, and the unexpected frothing of agent created serious maintenance and production problems. Freezing the munitions before opening the agent cavity to the atmosphere minimized the frothing.
3. Although freezing minimized problems associated with accessing the agent cavities of mustard rounds, it added a processing step. Only a small number of rounds was processed that way at JACADS, and no frozen rounds were introduced to the MPF for final processing.
4. The MPF can effectively process much larger residual agent heels than the 5 percent limit stipulated in the original EPA operating permit. Safe, effective processing of munitions was demonstrated, even with 100 percent of the original HD agent fill. A separate fur-

TABLE 2-6 Comparison of Selected Emissions (including those exceeding permit limits) for JACADS Trial Burns

Trace Metal	1998 Permit Limit (g/sec)	1992 Trial Burn (μg/dscm)	1992 Trial Burn (g/sec)	1999 Trial Burn (g/sec)
Arsenic	8.52 E-05	18.4	7.29 E-05	1.64 E-06
Cadmium[a]	2.98 E-05	No record	No record	<4.02 E-05
Chromium	2.87 E-05	2.25	8.91 E-06	<1.54 E-06
Lead	7.93 E-05	9.83	3.89 E-05	9.54 E-06
Mercury[a]	4.29 E-05	3.28	1.30 E-05	<2.25 E-04

NOTE: 1992 trial burn data were reported in micrograms per dry standard cubic meter (dscm) of stack gas. 1998 standards and 1999 trial burn data were reported in grams per second. 1999 stack gas volume was reported, after computation, at 3.96 dscm per second. 1992 stack gas volume, after computation, was reported to be 2.90 dscm per second. To facilitate comparison, 1992 micrograms per dscm were multiplied by 1999 stack gas volume per second times E-06. This converts the 1992 unit contaminant levels to total grams per second for the 1999 stack gas volume.

[a] Exceeds 1998 limits. The analytical data are the averaged results from four different trial burns conducted in 1999. For both mercury and cadmium, in three of the four analyses, the levels were below the detection limit. However, in one case for each metal, the measured levels were above the detection limits and in excess of the MACT standard.

Source: Adapted from U.S. Army, 1999b.

nace for processing liquid agent is not necessary for destroying projectiles filled with mustard agent.

5. Only one projectile out of 94,000 was found to be leaking HD from the agent cavity into the burster well at the time the energetics were to be removed. Eighty others were found to be leaking externally. The JACADS experience suggests that leakage will not be a major problem during disposal operations at PCD.
6. Emissions of cadmium and mercury in excess of standards were measured during the 1999 JACADS trial burn.
7. Except for charging SDS to the LIC afterburner during operations, secondary wastes were not treated as they were produced. Substantial inefficiencies that were created from having to handle massive quantities of secondary wastes at the end of JACADS disposal operations included protracted storage and monitoring; multiagent mixing in storage areas, thus complicating monitoring; the possibility of further contamination of igloos and surrounding areas; and increases in the risk of worker exposure and transportation-related accidents. Additional secondary waste was generated as a result of contaminating storage containers, such as the drums used for holding DPE suits.
8. Closure is an expensive, time-consuming, and complex process requiring thorough planning beginning concurrently with facility design. Delay in closure planning adds time and expense to the life-cycle cost estimate.

FINDINGS AND RECOMMENDATIONS

Finding 2-1. Trial burn results from the 1999 JACADS tests confirmed the required destruction and removal efficiency of 99.9999 percent when 4.2-inch mortar projectiles filled with mustard agent were incinerated through the metal parts furnace at a feed rate of 96 rounds per batch. Subsequently, almost 95,000 mustard projectiles were successfully destroyed in the JACADS MPF by mid-1999.

Recommendation 2-1. Based on the successful JACADS campaigns, the Army should evaluate a process design for Pueblo in which the munitions filled with mustard are processed through an MPF.

Finding 2-2. The 1999 JACADS trial burn did not include introduction of frozen projectiles into the metal parts furnace for final processing. Mustard in the frozen projectiles thawed before entering the MPF.

Recommendation 2-2. The Army should determine whether freezing projectiles before opening the mustard agent cavity to the atmosphere is necessary to mitigate frothing. If so, the Army should determine, by testing, whether frozen projectiles can be processed successfully through a metal parts furnace, or as an alternative, if it is feasible to allow the agent to thaw before the projectiles are fed to a metal parts furnace.

Finding 2-3. HT mustard-filled munitions were not processed at JACADS. HT and HD consist of similar chemicals and will most probably result in much the same products of combustion. Nevertheless, there is no evidence that testing and analysis of HT combustion have taken place.

Recommendation 2-3. Regarding HT, the Army should verify that the combustion of HT will produce results akin to the combustion of HD. These results should be considered in the development of the modified baseline process.

Finding 2-4. The 1999 JACADS trial burn results indicated that mercury and cadmium were emitted at unacceptable levels during the disposal of some mustard agent.

Recommendation 2-4. The Army should prove, through testing, an acceptable technique for capturing emissions of heavy metals—particularly cadmium and mercury—from the metal parts furnace when processing mustard-filled projectiles. An acceptable disposal plan for accumulated heavy metals must be included in the modified baseline process or any other process.

Finding 2-5. Secondary wastes, including dunnage and demilitarization protective ensemble suits, were reported to be successfully processed through the metal parts furnace (MPF) at JACADS, but only limited data on rates, operating conditions, and other parameters for handling these wastes in the MPF have been presented. The best way to handle spent carbon appears to be through the use of a micronizer system**.**

Recommendation 2-5. The Army should determine whether adequate data are available from JACADS to support the efficacy of processing secondary wastes in the metal parts furnace. If not, the Army should determine the additional tests required to confirm a disposal process. A plan based on these results should also be developed for handling and disposing of all secondary wastes from processing the Pueblo stockpile, including demilitarization protective ensemble suits and hoses, spent carbon filter materials, scrubber brine solutions, plant cleaning wastes, and dunnage.

3

The Modified Baseline Process

INTRODUCTION

The modified baseline process derived from the experiences at JACADS and considered in this report has been tailored to meet the requirements for disposal of the mustard agent munitions stockpile of projectiles and mortar shells at PCD. A parallel objective in the design and operation of this process is ensuring safety and minimizing health risks to workers, the surrounding populace, and the environment. Secondary objectives are minimizing the risks of prolonging the schedule and not exceeding the budgets for disposal processing of the PCD stockpile.

In both the baseline incineration system and the modified baseline process, energetics are removed in explosive containment rooms (ECRs) as part of the agent destruction operation in the munitions demilitarization building (MDB). A work-in-progress (WIP) buffer inventory is provided between the energetics removal step and the rest of the operation. The same type of energetics removal equipment is used in both the baseline system and the modified baseline process.

The modified baseline process concept differs from the baseline incineration system in two essential features (U.S. Army, 2000c):

1. In the modified baseline process, draining agent from a munition is replaced by freezing it inside the munition to minimize the foaming and frothing that occurred during accessing mustard agent at JACADS.
2. All agent is thermally oxidized in the MPF and its afterburner and the LIC has been eliminated. This step is justified by the results of the 1999 trial burn tests at JACADS, which demonstrated that 99.9999 percent of the agent was destroyed in the MPF and afterburner, as discussed in Chapter 2.

Major features of the baseline system and the modified baseline process are shown in Table 3-1.

DESCRIPTION OF THE MODIFIED BASELINE PROCESS

A preliminary flow diagram for the modified baseline process is shown in Figure 3-1.

Transport of Munitions

The plan for a modified baseline process for PCD envisions transporting munitions to and from the storage igloos in modified ammunition vans (MAVs), provided the risks are acceptable compared with those from using on-site containers (ONCs) at baseline system sites such as Tooele. No incidents occurred during the transport of munitions by MAVs from the Johnston Island storage area to JACADS during the disposal campaigns conducted there. A 1991 study by Mitre concluded that the risk associated with the use of MAVs was substantially the same as the risk with bulky, tightly sealed ONCs (Mitre, 1991). As this report was being prepared, Science Applications International Corporation (SAIC) was conducting a new risk analysis for PMCD (noted in Chapter 4). The use of MAVs may have other advantages: helping PUCDF meet the disposal schedule and being less expensive than ONCs to procure and operate.

Removal of Energetics

An existing munitions maintenance building at PCD, which has been used for years to process munitions manually, could be used for the removal of propellants from the 28,375 stockpiled 105-mm munitions that are complete rounds stored in field cartridge cases with propellant (see Appendix A). This process is known as reconfiguration. All of the remaining energetics in the munitions in the Pueblo stockpile would be removed by automated projectile/mortar disassembly (PMD) machines in ECRs, as they are in baseline system facilities. In the proposed modified baseline process for Pueblo, there are three ECRs in the MDB instead

TABLE 3-1 Comparison of Major Features of the Baseline Incineration System and the Modified Baseline Process

Process Step	Baseline Incineration System	Modified Baseline Process
Munitions demilitarization building (MDB)	The baseline munitions demilitarization building is a large two-story building containing three or more furnaces, equipment for energetics removal, agent draining and munitions-handling facilities, and a control room, corridors, and utilities.	This MDB is a smaller, one-story building containing equipment for energetics removal and munitions freezing and handling and a metal parts furnace (MPF) (and a deactivation furnace system, if energetics cannot be shipped off site).
Transportation and unpacking of munitions	Munitions are moved from igloos to the MDB in on-site containers (ONCs), which are received at a separate container handling building (CHB) and lifted to the second floor unpack area, where the munitions are unpacked and put on input conveyers to the MDB.	Munitions are moved from igloos in modified ammunition vans to the MDB ground floor loading dock instead of a CHB. Munitions are unpacked there and put on conveyers.
Removal of energetics (fuzes, bursters, propellant charges)	There are two explosion containment rooms (ECRs) within the MDB where energetics are removed by projectile/mortar disassembly (PMD) machines, one in each ECR. After removal, the energetics drop through feed chutes to the deactivation furnace system (DFS).	The MDB contains three ECRs, each with a PMD machine. These ECRs have lower blast level specifications than baseline system ECRs. Removed energetics are tested for agent contamination. Those passing the 3X test are stored for off-site shipment or for use as feedstock to a separate DFS, if that is required. Contaminated energetics will be disposed of separately.
Agent access and draining	Three multipurpose demilitarization machines remove the burster well, drain the agent, and then reinsert the burster well. The agent then flows into agent holding tanks.	Agent is not drained. Instead, it is first frozen. Then, a new machine either drills, cuts, or punches the munitions to access the agent.
Destruction of agent	The liquid agent is burned in a liquid incinerator (LIC).	Frozen agent-containing munitions are loaded on trays and processed through the MPF, where the agent is burned. There is no LIC.
Destruction of energetics	Energetics are burned in the DFS.	Energetics are shipped off site, if allowed. Otherwise they are burned in a DFS.
Decontamination of metal parts	Drained munitions, which may contain a heel of agent, are processed in a three-zone MPF and afterburner. Because liquid agent has been drained, less agent is fed to the MPF than in the modified baseline process.	Undrained munitions are processed in a four-zone MPF with an afterburner. Four zones provide the extra heating to burn the larger amounts of agent.
Treatment of furnace off-gases to convert sulfur and chlorine acid gases to salts and temper the off-gases	Exhaust gases pass through a pollution abatement system (PAS) that has a quench tower, a scrubber, a demister, a high-efficiency particulate air (HEPA) filter and carbon filters, and an induced draft blower. Each furnace has a PAS.	The MPF PAS is similar to, but larger than, the PAS for the baseline MPF in order to handle the higher salt loading produced from burning a larger amount of agent. If there is a DFS, it will have its own PAS.
Processing of brine	A brine reduction area (BRA) containing evaporators and drum dryers was included in the original baseline designs. At TOCDF, brine is being shipped off site, and the BRA is not used. It has been eliminated from newer baseline facilities.	It is assumed that the brine can be shipped off site. No BRA is included.
Monitoring of agent	ACAMS and DAAMS	The same systems are used, but fewer are required, because there are fewer furnaces and PAS systems.
Secondary Waste Treatment		
Treatment of dunnage (paper and wood waste products)	A dunnage incinerator was included in the baseline designs but has not been used. At JACADS, dunnage was burned in the MPF.	If dunnage is proven to be uncontaminated, it will be shipped off site. Otherwise it will be burned in the MPF.
Treatment of spent filter carbon	If uncontaminated, spent carbon is shipped off site. Otherwise, it is incinerated on site in the MPF or a micronizer and burner.	Same.
Treatment of spent decontamination solution	Spent decontamination solution (SDS) is injected into the LIC afterburner and burned.	SDS is injected into the MPF afterburner.

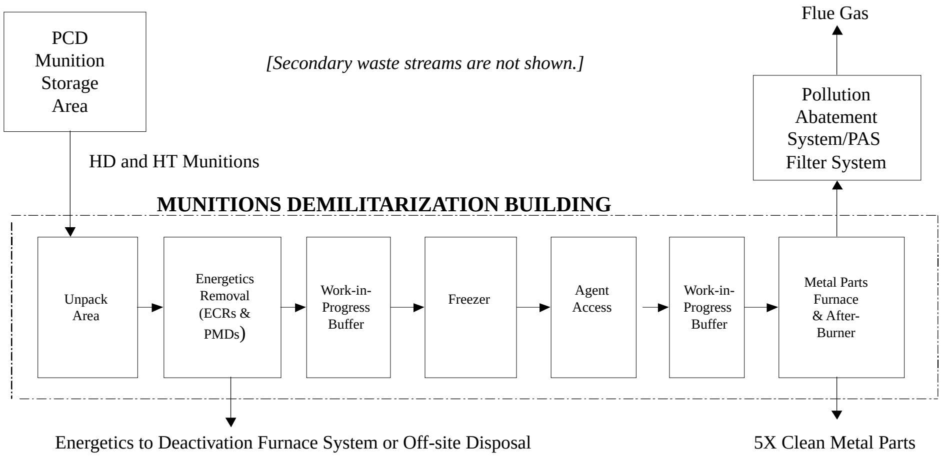

FIGURE 3-1 Pueblo modified baseline process.

of the two in baseline system facilities. A single PMD machine in each ECR can provide the necessary throughput, thus eliminating the need for a large WIP inventory of munitions waiting for processing (Tomanek, 2000a, 2000b).

The ECRs in the modified baseline process for Pueblo will probably have lower construction costs than the corresponding ECRs in baseline system facilities at other sites because the ECRs at Pueblo can be designed to withstand a lower explosive load from the relatively small mustard-filled munitions and will therefore require less concrete and reinforcement. ECRs at JACADS were designed to withstand simultaneous detonation of two 8-inch projectiles containing a total of 14 lb of explosives. The largest munition in the stockpile at Pueblo is a 155-mm round with 0.41 lb of explosives. Current plans are to process three rounds simultaneously on a PMD, a total design load of 1.23 lb of explosives in an ECR.

ECRs, with only one PMD machine each, have the added advantage that if an ECR becomes contaminated, the other two PMD machines in their separate ECRs can continue operations. Thus, the impact on facility throughput from a contaminated ECR is lower than if there were several PMD machines in fewer ECRs.

A preliminary estimate is that 1,000 munitions from the PCD stockpile will leak agent during transport to the ECRs. Leakers would be repacked in sealed overpack containers, safely stored, and later destroyed (Battelle, 1999).

Energetics Disposal

There are two options for disposing of energetics. PMCD prefers the simpler option of sending them to existing off-site treatment, storage, and disposal facilities (TSDFs) that routinely dispose of similar energetics. Before energetics removed from chemical munitions can be shipped off site, however, efficient analytical procedures must be applied to ensure that the energetics meet the required 3X decontamination level.[1] A contract with a TSDF to take the energetics, as well as permission to ship them there, would also be required. PMCD conducted a survey of TSDFs and found several willing to accept energetic materials designated 3X. Whether off-site transport of uncontaminated energetics will be permitted has not been determined, but a study of transportation risks is under way (Venkatadri, 2000).

If off-site transport of energetics is not permitted, the second option is on-site disposal. If this is done in the modified baseline process, they would be incinerated in a DFS with a dedicated PAS, similar to the one in the baseline system.

Obtaining approvals for off-site transport might cause delays. If the destruction of energetics must be completed by the CWC deadline, PMCD should set a date by which construction of the DFS must be started if no off-site permit has been received or if the receiving facility does not have a valid permit. A permit for DFS construction should be relatively easy to obtain because of its successful use at both JACADS and TOCDF. However, enough time must be allowed in the schedule for permit application and approval. In view of the opposition to incineration by some Pueblo stakeholders, the prompt receipt of a DFS permit cannot be assumed.

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[1] The 3X decontamination level refers to solids decontaminated to the point that the agent concentration in the headspace above the encapsulated solid does not exceed the health-based, eight-hour, time-weighted average limit for worker exposure. The limit for HD is 3.0 μg per cubic meter of air. Materials classified as 3X may be handled by qualified plant workers using appropriate procedures but may not be released to the environment or sold for general public reuse. In specific cases in which approval has been granted, a 3X material may be shipped to an approved hazardous waste treatment facility for disposal in a landfill or for further treatment.

Finding 3-1. The Army has not determined when a commitment to an on-site deactivation furnace system as part of a modified baseline process at Pueblo must be made if a permit for the off-site transport of energetics has not been received.

Recommendation 3-1. The Army should develop a process and schedule to determine when a decision must be made between the off-site transport of energetics or their on-site disposal in a deactivation furnace system. To avoid schedule delays, the decision mechanism must account for uncertainties in the permitting process.

Decontamination of Energetics

Although not many cases are expected, any energetic materials contaminated with agent must be decontaminated or destroyed. One alternative is to dissolve the entire munition in an acid bath (Battelle, 1999). Another is to destroy the energetics in the Army's explosive destruction system (EDS),[2] a portable self-contained chamber in which two to six bursters can be handled at one time (Thompson, 2000a; U.S. Army, 2001a).

Freezing of Projectiles That Contain Agent

In the modified baseline process for Pueblo, following removal of bursters and fuzes, munitions will be frozen prior to accessing the agent to minimize foaming or frothing. Six freeze rooms of a standard industrial design will operate at –20°F to –10°F. Munitions will have a residence time of 11 to 15 hours, based on a heat-transfer model for freezing developed by SAIC (Coughlin, 2000). After removal from the freeze room, munitions will remain frozen below 55°F, the freezing point of mustard, for 3 hours. The freezing operation is an important design consideration for the modified baseline process because it will minimize the maintenance problems from frothing that sometimes occur when mustard munitions are processed at normal temperatures through MDMs.

This feature of the modified baseline process is based on the experience at JACADS, where 201 rounds were frozen before the agent was accessed. The frozen rounds did not exhibit foaming or frothing during the agent accessing operation (U.S. Army, 2001a). However, information provided to the committee indicates that the frozen rounds had thawed (i.e., were not in a frozen state) by the time they entered the MPF (U.S. Army, 2001a). Although the modified baseline process design calls for putting frozen rounds into the MPF, there is no prior experience with the thermal oxidation of mustard entering in the frozen state. Heating frozen projectiles in the MPF could potentially result in the erratic ejection of agent, causing spikes in pressure and temperature; solid agent might even be propelled against internal surfaces of the MPF. Apparently, there are no data bearing on this issue from JACADS or elsewhere (U.S. Army, 2001a).

Finding 3-2. If the Army intends to use the freezing process at Pueblo, data on the behavior of frozen rounds will be essential to confirm the feasibility of a modified baseline process that integrates freezing of the munitions for agent accessing prior to their treatment in the metal parts furnace.

Recommendation 3-2. The Army should obtain experimental data on the behavior of frozen mustard rounds fed into the metal parts furnace (MPF). At a minimum, these data should demonstrate that:

- Frozen rounds (HD and HT) can be processed in the MPF without adverse consequences from the simultaneous presence of agent in solid, liquid, and gas phases, which might lead to spiking of furnace temperatures and pressures from agent confinement and rapid subsequent release in the gaseous phase.
- Complete volatilization and destruction of the frozen agent in the MPF can be achieved.
- Solid agent will not be ejected and propelled against internal surfaces of the MPF.
- Temperatures and residence times necessary to achieve destruction have been determined.

Finding 3-3. The committee could not determine whether an experimental program to verify the feasibility of processing frozen mustard rounds in the metal parts furnace would delay the disposal schedule for the Pueblo Chemical Agent Disposal Facility. However, the need for experimental verification is not only a technical consideration, but also a regulatory issue. Although the committee did not evaluate the regulatory climate at Pueblo concerning this issue, obtaining a permit for a one-of-a-kind modified baseline process may be more difficult and more time consuming than obtaining a permit for the baseline system, which has been successfully demonstrated at two facilities and supported with extensive trial burn data.

Recommendation 3-3a. The Army should evaluate the risk of delay in obtaining a permit for the proposed modified baseline process at Pueblo that includes the treatment of frozen mustard rounds in the metal parts furnace (MPF). The evaluation should take into account the permitting experience for the process used at JACADS to freeze 201 mustard rounds and feed partially thawed, 100-percent-filled mustard agent rounds into the MPF.

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[2] The EDS is being developed as part of the Army's Non-Stockpile Chemical Materiel Disposal Program for treatment of explosively configured recovered munitions that had been buried on sites used in the past by the Army for training.

Recommendation 3-3b. The Army should evaluate the efficacy of allowing frozen munitions to thaw before feeding them into the metal parts furnace of a modified baseline process in a manner similar to the procedure used at JACADS. If the Army intends to include this process step, associated safety, design, maintenance, and regulatory approval issues should be assessed.

Opening of Munitions to Access Agent

In the modified baseline process for Pueblo, frozen munitions will be conveyed to six agent accessing machines operating in parallel and sized to handle 27 munitions per hour each (Tomanek, 2000a, 2000b). These will not be baseline system MDMs but new machines that would have to be developed and tested. Prototype testing would take place at the Chemical Demilitarization Training Facility in Aberdeen, Maryland.

The new machines will not pull the burster well; they will instead open the agent cavity and verify that it is open (see Appendix A for cross-sectional views of projectiles). Four options were originally considered (Thompson, 2000b):

- drilling or milling the top of the munitions off center
- cutting through the burster well
- punching the munition from the side to penetrate the shell
- pressing the adapter base (the fitting at the top of the shell casing into which the fuze housing is inserted) down into the munition so the top of the shell is opened

The Army has eliminated the first two options, and it is expected to recommend either the third or fourth option by mid-August 2001 (Thomas, 2001).

Baseline system facilities at Tooele, Utah; Anniston, Alabama; Umatilla, Oregon; and Pine Bluff, Arkansas, are or will become operational prior to the PUCDF. Disposal campaigns at all these facilities but Pine Bluff are scheduled to process mustard agent munitions and therefore will have to deal with the foaming and frothing problem identified at JACADS, if it arises. Currently, freezing is not planned at any of these facilities. An alternative method (a froth collection system on the MDM) has been designed for capturing agent at all sites processing projectiles if foaming or frothing occurs during agent accessing operations (personal communication from Conrad Whyne, Project Manager for Chemical Disposal Operations Team, March 28, 2001).

Finding 3-4. The machines proposed for accessing agent in the modified baseline process differ from the multipurpose demilitarization machines used for this purpose at JACADS. The method proposed for accessing mustard agent should open the munition cavity sufficiently to enable complete destruction of the agent in the metal parts furnace.

Recommendation 3-4a. The Army should demonstrate that the method selected for accessing mustard agent opens the munition agent cavity sufficiently to enable complete destruction of the agent in the metal parts furnace.

Recommendation 3-4b. If the development and testing of the machines for accessing agent in the modified baseline process would delay disposal operations past the Chemical Weapons Convention deadline, the Army should consider installing another technology at Pueblo.

Finding 3-5. Freezing mustard munitions to avoid problems with foaming/frothing of agent is not currently planned for any of the baseline facilities in the continental United States.

Recommendation 3-5. The Army should determine whether the method proposed for capturing mustard agent during agent accessing at baseline system facilities could be adapted for use at Pueblo with a potential savings over the cost of developing and testing freezing methods.

Processing of Agent-Containing Munitions in the Metal Parts Furnace

Unlike the baseline system, which uses a LIC to destroy most of the agent, in the modified baseline process, all agent is destroyed in the MPF and its afterburner. Consequently, the MPF is the critical element in the modified baseline process. Sufficient machinery for accessing agent and sufficient WIP buffer inventory will be necessary to ensure that facility throughput is determined by the capacity of the MPF and that the MPF is not starved for input feed materials.

Several MPF design alternatives were considered:

- a furnace with three zones, much like the one at JACADS
- a furnace with four zones
- parallel three- or four-zone furnaces

PMCD evaluated the trade-offs among these alternatives and reports that the single four-zone furnace appears to be the best and most operable option (Thompson, 2000c). The nominal design temperature setting for the first zone is 1,450°F and for zones 2, 3, and 4 is 1,600°F. HD vaporization rate modeling by Continental Research and Engineering (CR&E) for fully loaded munitions in a four-zone MPF that includes top and bottom water sprays in zones 1, 2, and 3 to control the temperature and therefore the rate of HD vaporization indicates that the peak HD vaporization rates, which occur in zones 1 and 2, do not significantly overlap or exceed the maximum capacity of the MPF afterburner, the PAS, the PFS, or the induced draft fans (CR&E, 2000). For 5X decontamination, zones 3 and 4 provide a 1,600°F furnace environment for thermal desorption of any residual mustard or breakdown products and for heating to and holding the munitions at >1,000°F for at least 15 minutes. At the recommendation of a PMCD consultant, a four-zone MPF versus a three-zone MPF was used to increase throughput by 33 percent, which would allow the 780,078 munitions in the Pueblo stockpile to be processed in approximately 25 months (U.S. Army, 2000a). The design throughput basis for the four-zone MPF is provided in Table 3-2.

A number of improvements are being incorporated into the design (Webster, 2000). The conveyers will have a higher load capacity than those in the normal baseline system design and will have individual motor-driven rollers. Water-spray flow valves will be upgraded. The inlet gasket channel will be redesigned to prevent dislodging of the gasket. A third standby automatic continuous air monitoring system (ACAMS) monitor will be installed in the emissions monitoring system. The MPF will be the only source of stack emissions unless a DFS is also installed. The furnace(s) and the downstream PAS will be sized to accommodate the lower barometric pressure at Pueblo (elevation 4,600 feet).

Off-gas emissions from the modified baseline process MPF will pass through a separately fired afterburner maintained at a temperature of 2,000°F. The committee was told that the afterburner design is patterned after the successful afterburner operations at JACADS and TOCDF (Webster, 2000). The key design parameter for the afterburner is to have a one-second residence time at 2,000°F (CR&E, 2000). Off-gas emissions then pass through the PAS, which includes high-efficiency particulate air (HEPA) and carbon filtration. Metal parts emerging from the MPF will be disposed of as scrap metal.

An extremely important operating requirement for the MPF is the safe shutdown and restarting of the unit if there is a loss of the air supply for combustion, loss of exhaust fan capacity, or both. A loss of electrical power is the usual cause of such an occurrence. If this happens, there is a significant probability that the munitions in the MPF will still be vaporizing uncombusted agent when the furnace temperature drops below 1,200°F. At JACADS, the solution was to cool the furnace to 400°F with water sprays, then to back the trays into a buffer storage zone upstream of the MPF (MR&E, 1996). Once the furnace was restarted, the trays were processed normally.

At Anniston and Umatilla, diesel-powered emergency electrical power systems sized to handle the power requirements of the facilities will start up if normal electrical power fails. These standby systems are tested regularly. Pueblo will also have a standby system.

Finding 3-6. Continuous throughput and safe operation of the metal parts furnace are the most critical aspects of the proposed modified baseline process for Pueblo. The furnace can be sized to operate safely and reliably with substantial loading.

Recommendation 3-6. A modified baseline process at Pueblo should include a four-zone (rather than three-zone) metal parts furnace with design provisions to ensure safe shutdown and restarting in the event of operational upsets, such as a loss of electrical power, combustion air supply, or exhaust gas capability.

Treatment of the Off-Gas from the Metal Parts Furnace

As in the baseline system, the gases from the MPF afterburner of the modified baseline process are passed through the quench tower and scrubber of the PAS to cool and neutralize acidic gases (mostly HCl) formed from the combustion of agent. Roughly 1.6 lb of salts are formed for every pound of HD agent oxidized. Because more agent will be oxidized per hour in the MPF of the modified baseline process than in the baseline system, the size of the quench tower will be increased to accommodate the larger volume of acid gases. Larger and better strainers will be added to the spray nozzles, and improved instrumentation will be installed. From the quench tower, the gases pass through a venturi scrubber, a scrubber, and a mist eliminator. The gases are then reheated and drawn by two induced-draft fans in series through the PAS filter system (PFS), which has activated carbon filters with HEPA filters upstream and downstream of the carbon filters. The PFS is a new component for baseline system facilities and will first be used at Anniston, Umatilla, and Pine Bluff. The PFS filters will be tested during systemization at Anniston (personal communication from Conrad Whyne, Deputy Project Manager for Chemical Stockpile Disposal, March 28, 2001).

Models were used to obtain vapor rate profiles in the MPF and they show a more uniform profile for the four-zone MPF than the three-zone MPF used for the fully loaded HD muni-

TABLE 3-2 Summary of Materials to Be Processed in a Four-zone MPF at Pueblo

Munition Type	Munitions per Tray	Agent (lb/tray)	Metal (lb/tray)	Cycle Time (min/tray)	Peak Rate (munitions/hr)	Peak Agent (lb/hr)	Metal (lb/hr)
105-mm projectile	96	288	6,166	36	160	480	10,277
155-mm projectile	48	562	7,414	37	77.8	911	12,023
4.2-inch mortar	96	576	4,352	44.5	129.4	777	5,867

Source: Adapted from CR&E, 2000.

tion trial burn at JACADS. This provides some assurance that the formation of products of incomplete combustion (PICs) should be no worse than those experienced during the 1999 trial burn at JACADS (U.S. Army, 1999b).

Particulate emissions from the MPF that pass through the PFS are expected to be captured by the HEPA filters. If any dioxins, furans, or other PICs are emitted, they are expected to be adsorbed on the carbon filters.

PIC data were well documented in the committee's 1999 report *Carbon Filtration for Reducing Emissions from Chemical Agent Incineration*, which provided the results of an in-depth statistical review of trial burn data from JACADS and TOCDF (NRC, 1999a). In addition to particulates and hydrogen chloride, the emissions data encompassed measurements for 22 elements, halogen-containing species, 204 trace organics, light hydrocarbons with boiling points lower than 100°C (212°F), and nonvolatile hydrocarbons with boiling points higher than 300°C (572°F). The report noted, "For JACADS and the TOCDF, the vast majority of emittants that were analyzed are below the analytical detection limit." For the data analyzed, the report also noted that "the reported emission concentrations are among the lowest for all hazardous waste incinerators in the EPA's Hazardous Waste Combustor Emissions Database." More recent data evaluated by the committee on formation of PICS can be found in the JACADS 1999 trial burn report (U.S. Army, 1999b). The total toxicity equivalent from dioxins and furans reported was less than 1.86 E-11 g/sec, which is the detection limit. For 16 PCBs, the total toxicity equivalent was also below the detection limit of 3.02 E-10 g/sec. None of the 138 semivolatile organic compounds that were sampled was detected. The committee believes that this is sufficient evidence to indicate that PIC formation is not a concern.

Formation of PICs in the downstream off-gas treatment units (PAS and PFS) is not expected, as the temperatures of these units are well below PIC formation temperatures. The off-gas is quenched rapidly after the high-temperature afterburner, minimizing the time at temperature where PICs may form. The committee believes that PICS are no more of a concern in the modified process than in the current operating units of the baseline system.

Finding 3-7. The control of emissions of cadmium and mercury by the PFS HEPA and carbon filters has yet to be demonstrated. The PFS filters will be tested during systemization at Anniston Chemical Agent Disposal Facility.

Recommendation 3-7. Tests and analyses for the control of metal emissions, especially cadmium and mercury (elemental and total) and organics (products of incomplete combustion), should be conducted for the metal parts furnace and afterburner and PAS/PFS prior to completion of the design for the modified baseline process to ensure that emissions are within required limits. Necessary control technologies should be incorporated into the plant design.

Handling of Brine Generated in the Quench Tower

A brine reduction area, in which brine is evaporated and dried to salt, is a feature of the JACADS and TOCDF baseline system designs. The brine qualifies as a RCRA hazardous waste and can be shipped off site (after appropriate testing) and disposed of in a permitted TSDF. This is now being done at TOCDF, is planned at the other baseline system sites, and is the preferred alternative for the modified baseline process at Pueblo. The amount of brine expected over the life of Pueblo stockpile disposal operations is 14.5 million gallons (WIPT, 2000a, 2000b, 2000c).

Handling of Secondary Wastes

Secondary wastes include SDS, DPE suits, spent carbon, dunnage, slag, and ash. In the modified baseline process, the plan is to process agent-contaminated dunnage and DPE suits through the MPF. These materials were reported to be successfully processed in the MPF at JACADS and, therefore, should be processed similarly at Pueblo. The throughput rates remain to be demonstrated. SDS was processed in the LIC afterburner at JACADS, which supports the likelihood that SDS can be treated in the MPF afterburner in the modified baseline process, but this remains to be proven (Thompson, 2000d).

The disposal procedures for spent carbon have not been determined. Carbon may be processed through the MPF, or through the DFS if one is included. Another alternative may be to use a micronizer to grind the carbon to a fine powder, which could then be burned in a combustion chamber coupled with the micronizer (personal communication from Gary W. McCloskey, PMCD JACADS Site Project Manager, June 22, 2000). Uncontaminated carbon, dunnage, and slag (from the MPF afterburner burning SDS and ash from the MPF) will be shipped to permitted hazardous waste disposal facilities after they can be shown to be substantially free of agent. Analytical techniques to measure agent in spent carbon and liquid media are being evaluated. These issues are discussed at length in an NRC report on monitoring at chemical stockpile disposal facilities (NRC, 2001).

Finding 3-8. Secondary wastes, which include contaminated dunnage, DPE suits, spent decontamination solution, and contaminated spent carbon, were treated at JACADS using a combination of furnaces and afterburners, or a micronizer and a burner system for spent carbon. Uncontaminated dunnage and spent carbon, slag, and ash were shipped off site to permitted waste disposal facilities after being tested to ensure they were suitable for shipment.

Recommendation 3-8. Lessons learned at JACADS from the disposal or decontamination of demilitarization protective ensemble suits and dunnage in the metal parts furnace should be incorporated into the design and operation of the comparable furnace (MPF) of the modified baseline process. Spent decontamination fluid should be injected into the MPF afterburner (or deactivation furnace system [DFS] afterburner) if it cannot be shipped off site. Similarly, contaminated spent carbon can be processed through either the MPF or the DFS if there is one. Uncontaminated dunnage and spent carbon, slag, and ash can be shipped off site to permitted waste disposal facilities after being tested to ensure they meet all requirements for off-site disposal.

Monitoring of Agent and Other Pollutants

The agent monitoring system for a modified baseline process at Pueblo would be patterned after the one at JACADS and the other baseline incineration system facilities. Automatic continuous air monitoring system (ACAMS) and depot area air monitoring system (DAAMS) units will be installed at various locations inside PUCDF and at other spots around the perimeter of the PCD. ACAMS monitors provide for rapid detection of the presence of agent in air; DAAMS monitors provide accurate measurements of actual agent concentrations averaged over a period of time. A third, standby ACAMS monitor will be added to the MPF to ensure that monitoring is not interrupted. Because there is no LIC, and possibly no DFS, both of which require ACAMS monitors, fewer ACAMS will be needed in the modified baseline process than in a baseline system.

In 1995, the amendments to the Clean Air Act included requirements for maximum achievable control technology (MACT) for pollutants, including dioxins and metals. The EPA has since promulgated regulations that will have to be met by a modified baseline process for the Pueblo site (EPA, 1999). In addition, EPA is reviewing the effects of dioxins on human health because some evidence indicates dioxins may be more harmful in the food chain than previously thought (Kaiser, 2000). If dioxin emission standards are modified, analytical procedures will need to be reviewed.

At the present time, continuous monitoring of mercury, dioxins, and PIC emissions from incinerators is not required, and the Army has no plans for continuous monitoring at PUCDF or any other chemical agent disposal facility, except during trial burns. Analytical equipment for truly continuous monitoring has not yet been proven in commercial operations but is under development. Although the PFS HEPA filters are expected to capture particulates and the activated carbon filters are expected to adsorb and hold emissions of mercury, dioxins, and PICs, these emissions are of great concern to the stakeholders living around stockpile disposal facilities, who may not be satisfied with these measures. Developing monitors for metals and organics and conducting stack tests could go a long way toward demonstrating the Army's sensitivity to the concerns of the surrounding communities.

Finding 3-9. Monitoring systems currently used at existing baseline system facilities appear to be adequate for use in a modified baseline process at Pueblo. The addition of a third, standby automatic continuous air monitoring system unit in the area of the metal parts furnace (MPF) is a reasonable modification in light of the increase in agent throughput over the throughput for the MPF of the baseline system. Notwithstanding the current lack of regulatory requirements for continuous monitoring, further development of monitors for metals and organics is likely to be beneficial for confirming clean emissions. This would also support the Army's interaction with local citizens by making definitive emissions data more available to the public.

Recommendation 3-9. The Army should evaluate state-of-the-art analytical tools for continuous monitoring of emissions of metals, dioxins, and products of incomplete combustion. If they are effective, the Army could install them at chemical agent disposal facilities where applicable. If continuous monitors are not effective, the Army could conduct stack tests for dioxins/furans, mercury, and organics at suitable intervals to provide some additional assurance to the surrounding communities that the modified baseline process is working properly.

Infrastructure

Regardless of which technology is chosen for destruction of the chemical munitions stockpile at Pueblo, infrastructure to provide electrical power (including standby generating facilities), water, sewage disposal, natural gas, and road access will be necessary. Recognizing this, PMCD has obtained approval from government and regulatory authorities to allow construction to begin on some infrastructure facilities that will be required regardless of the technology selected.

Overall Throughput

The committee was provided an overview of throughput specifications for a modified baseline process design for Pueblo (Tomanek, 2000a, 2000b). The rate at which the MPF can process munitions or waste is the rate-limiting step in the design. All other equipment and feed conveyors in the MDB, including those in the unpack area, the munitions freeze area, the agent accessing area, and the munitions staging area, will be sized to meet the maximum MPF throughput rates. The rates per day are 3,105 4.2-inch mortar shells, 3,840 105-mm projectiles, or 1,867 155-mm projectiles. At JACADS, overall availability[3] was limited by the brine-

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[3] *Availability*, the amount of time in a specified period that the facility (or a component of the facility) is ready to process feed whether or not feed is available, is expressed as a percentage of the specified time period. Maintenance and repair down time, for example, reduce availability.

TABLE 3-3 MPF Design Throughput Rates for Processing Munitions

Munition Type	Peak Rate (no./hr)	Furnace Availability (%)	Regulatory Rate Restriction[a] (%)	Average Throughput (no./hr)
105-mm projectile	160.0	60	75	72.0
		100	75	120.0
155-mm projectile	77.8	60	75	35.0
		100	None	77.8
4.2-in. mortar	129.4	60	50	38.8
		100	50	64.7

[a] The restrictions provide a period of conservative, reduced-rate operation between the time a trial burn has been completed and the data from the trial burn have been analyzed and finally approved. Generally, fewer munitions are placed in a tray when the unit is operating under the restriction. The restriction applies to baseline operations.

Source: Jacobs Engineering, 2000.

processing capacity, but in the modified baseline process, brine will be shipped off site.

The design basis for MPF availability for processing munitions in the modified baseline process is 60 percent. Another 10 percent availability is required to handle secondary wastes, so the total required MPF availability is 70 percent. The MPF availability at JACADS in operations on 4.2-inch HD mortar projectiles was 53 percent, but anticipated improvements in conveyers, water spray valves, gate gaskets, the continuous emissions monitoring system, and expansion of the PAS in the modified baseline process are predicted to raise overall MPF availability to 70 percent or higher (Tomanek, 2000a, 2000b). Table 3-3 provides MPF availability rates for processing munitions (but not secondary wastes).

The single MPF is coupled to upstream activities in the MDB. As one example of a problem that might arise in this tightly coupled system, the ability of the PMD lines to supply the right quantities of energetic-free munitions to the freezers and agent access machines to keep the MPF full may be critically dependent on a correct assumption about the number of entries into the ECRs for maintenance and repair. Possible methods of mitigating this problem may include providing more agent-accessing machines for redundancy or providing for larger WIP buffers just before the MPF. The committee could not quantitatively assess the potential effects of these methods for ensuring optimum use of the MPF.

Closure of the Facility

One of the lessons learned from the JACADS experience is that planning and designing for the closure of a facility at the time of initial design are extremely important and can greatly reduce the time and costs of closure. Rapid closure will be particularly important for PUCDF, because the Pueblo community wants to redevelop a large portion of PCD property for commercial purposes as soon as possible after the stockpiled munitions have been destroyed. In fact, some redevelopment has already begun (see Chapter 4) in areas of PCD known to be free of agent and environmental contamination. In any case, a safe, efficient, rapid closure of PUCDF would be beneficial and cost effective.

According to current plans, the portion of PCD not being considered for commercial development will be converted into a wildlife refuge. The exact end-use requirements of the site have not been determined; some areas are classified for residential use, others for industrial use, and still others for a wildlife refuge.

No closure plan has been developed, but one will be prepared for the RCRA permit application (U.S. Army, 2000c). Assuming proper attention is given to closure issues during facility design and operation, the closure of a modified baseline process facility should be easier than closure of a baseline system facility for several reasons. First, because there is no burster well removal step and no draining of agent from the projectiles, there should be less agent contamination in the MDB. Second, there are no agent pipes, pumps, or storage tanks. Third, freezing would reduce both the ambient vapor pressure of the agent (so agent spread would be limited) and the chance of liquid spills in the agent accessing area. Fourth, if the floor of the freezing and agent accessing area is a welded, seamless sheet of stainless steel, this sheet could be removed at closure, cut up, and processed through the MPF.

The Stockpile Committee is preparing a report for release in 2001 on the ongoing closure activities for JACADS. This report could provide useful guidance to the Army for making timely closure decisions regardless of the technology selected for implementation at Pueblo.

Finding 3-10. Although the modified baseline concept is derived from the lessons learned at JACADS, no closure plan has been developed. The committee found no evidence of explicit considerations of closure in the design or design criteria of the modified baseline process for the PUCDF.

Recommendation 3-10. Engineering, design, and construction plans for the Pueblo Chemical Agent Disposal Facility should incorporate all of the requirements for closure identified at JACADS and other baseline system facilities. Value-engineering studies should be initiated to review all existing designs for conformance to closure principles identified in the forthcoming NRC report on the closure of JACADS. The Army should also initiate closure planning as soon as possible.

CRITICAL DECISIONS FOR PMCD AND PUEBLO

In a broad-band contractor briefing to the committee on July 28, 2000, the following 10 decision areas were identified for the modified baseline process (U.S. Army, 2000d):

- manual/semimanual versus machine-based operations to remove energetics
- removal of energetics in a separate facility versus in a facility integrated into the MDB
- off-site versus on-site treatment of energetics
- use of ONCs/container handling building versus use of MAVs
- agent access/freeze operation versus no-freeze access
- secondary waste treatment options
- configuration of the MPF
- improvements in the PAS
- PFS versus no PFS
- on-site versus off-site brine treatment

The following evaluation criteria were recommended for deciding on the efficacy of modifications (U.S. Army, 2000d):

- safety
- environmental issues, including permitting
- schedule risk, including the feasibility of meeting the CWC deadline
- cost risk

The "goal was to select the configuration that was judged to have the greatest probability of meeting the CWC deadline while maintaining programmatic safety and environmental performance goals" (U.S. Army, 2000d). Some trade-offs could be necessary because the "benefits from changes could be outweighed by [the] length of [the] implementation/approval process. Mature, demonstrated technologies will likely be approved more quickly" (U.S. Army, 2000d). In short, the final process configuration would only be apparent after each component of the modified baseline process had been evaluated separately. Delays in obtaining permits and approvals of the modifications could make a modification impractical compared with the baseline system because the treaty deadline might not be met.

The following modifications were "recommended" at the time of the briefing (U.S. Army, 2000d):

- Pursue explosive separation as a remote manual operation in an ECR.
- Perform explosive separation in a separate facility with PMDs/ECRs, assuming state regulatory authorities will agree to an accelerated permit schedule.
- Pursue a modified DFS and off-site treatment on parallel paths until state regulatory authorities indicate whether off-site shipment is viable.
- Eliminate the container handling building from the modified baseline process design, and design a buffer area to support transport of the munitions by MAVs.
- Continue to investigate alternative agent-accessing equipment (alternatives to MDMs will be essential in order to meet overall throughput rates).
- Process DPE suits in the MPF, SDS in the MPF afterburner, and carbon in the DFS (if available); pursue off-site disposal of SDS on a parallel path.
- Use a single, four-zone MPF.
- Use a PAS with increased capacity.
- Incorporate the PFS in the modified baseline process for Pueblo because it has the best chance of being accepted by the public and regulators.
- Ship brine off site for processing.

During the preparation of this report, only five decisions appeared to be firm: (1) not proceeding with manual/semimanual removal of energetics; (2) integrating the energetics removal step into the MDB rather than in a separate facility; (3) using a single, four-zone MPF; (4) using a PAS with increased capacity; and (5) incorporating a PFS. The other decisions were under investigation, awaiting more technical information (e.g., agent-accessing approaches), or contingent on external regulatory approvals.

Although it may take some time to obtain additional technical information, prepare cost estimates, and prepare material for regulatory approval, at the time this report was prepared, no decision tree or network had been developed identifying milestone dates by which decisions had to be made to meet the CWC treaty deadline (April 29, 2007). For each decision, a milestone date must be established, at which point the modification must either be approved or abandoned. For example, approval for a decision to use MAVs must be obtained or orders for the procurement of ONCs and the design of the associated container handling building must go forward to avoid delaying the disposal schedule.

PREPROJECT PLANNING FOR A MODIFIED BASELINE PROCESS

PMCD and its contractors are experienced and knowledgeable organizations that have been involved in the design and construction of five baseline incineration system facilities. It is apparent that some of the critical decision points for Pueblo are engineering design decisions that must be made by project personnel based on technical issues, cost effectiveness, and their impact on the duration of construction and operations. An example involves determining the most cost-effective way of keeping emissions of heavy metals below prescribed regulatory standards. Another is whether fully frozen munitions can be introduced safely into the MPF, or if another approach would be equally safe and more cost effective—perhaps one that does not require freezing. A third example is whether the new machinery to cut open or drill frozen munitions can be developed, tested, and acquired in time to meet the destruction schedule of the Pueblo stockpile by the CWC treaty deadline date.

Other decisions will be made by regulators or other agencies that are not under the control of managers for the project. An example is whether MAVs or ONCs will be permitted for transporting munitions from the PCD storage area to PUCDF. Another example is whether energetics will be permitted to be shipped off site for destruction or whether a DFS must be installed as part of the PUCDF.

A well-conceived preproject plan should be developed to anticipate and account for such exigencies. The ideal plan would be in the form of a decision network showing the various paths from alternative decisions. The paths would be measured and weighted in terms of the probabilities of completing them in a prescribed time. For every alternative outcome at each of the decision points, a path should lead to the completion of stockpile destruction by the CWC treaty date. If a path does not meet the treaty date, then either the decisions on that path must be made earlier or that path must be eliminated from consideration. For a path to be viable, the decisions on that path must be within the authority of project managers or steps must be taken as soon as possible to correct this situation.

One of the examples given above involves off-site shipment. If there is some likelihood of off-site transport being permitted, then this remains a viable option. But a date for the permitting decision should be determined, after which this option should no longer be considered viable. One of the functions of preproject planning is to identify these issues before it is too late.

The schedules shown to the committee were simply lists of things that had to be done and the time estimated to complete each of them. Alternative paths that would be generated as decisions were made were not evident, nor were any time-related probabilities assigned. The “schedules” presented to the committee are extremely vulnerable to unforeseen or external events. Moreover, the committee was not provided with total project cost estimates, even of a conceptual or preliminary nature. Without these estimates, it is extremely difficult to evaluate engineering decisions and select the most cost-effective technologies. Based on the lack of documentation, the committee concluded that an adequate preproject plan for a modified baseline process at Pueblo may not exist. If this is true, the completion of the project on schedule and within budget is unlikely.

Fortunately, industry and some government agencies have a good understanding of what constitutes best practices in project management and preproject planning for complex, time-critical projects. The standards and good practices for preproject planning have been developed by several organizations, such as the Business Roundtable, the Construction Industry Institute, and the Federal Facilities Council (BRT, 1997; CII, 1991, 1994; FFC, 1998).

Comparing the status of PUCDF planning with the characteristics of successful megaprojects identified in a 1999 NRC report (NRC, 1999b) indicates that some characteristics categorized as “essential to success” and “important to success,” such as schedules and risk analyses required by Office of Management and Budget Circulars A-94 and A-11 for projects undertaken by government agencies, are not included in PUCDF planning (OMB, 1992, 1998). “Essential” conditions for success occur when:

- schedules and cost estimates are prepared together based on the work breakdown structure and production rates, crew size, physical constraints, and other time-impacting issues
- schedules, like cost budgets, include a contingency increment, the magnitude of which must be known to the project manager so that it can be considered continuously in making management decisions
- benefits of early completion of the work are high, and schedules are aggressive and planned so as to complete the project as early as possible
- the schedule is aggressive and pursued vigorously to minimize exposure to internal and external changes
- milestones, including owner actions, are clearly defined, listed, tracked for performance, and continuously monitored against performance

Conditions considered “important” to success occur when:

- schedule contingencies decrease as the work progresses and fewer unknowns remain to be resolved
- risk analysis and probability techniques are applied to task durations
- independent reviewers evaluate the assumptions used in making the schedules and confirm the realism in the major milestones and completion date(s)

Further guidelines found in OMB Circular A-94 for on-time completion of projects are (OMB, 1992):

> 9. **Treatment of uncertainty**. Estimates of benefits and costs are typically uncertain because of imprecision in both underlying data and modeling assumptions. Because such uncertainty is basic to many analyses, its effects should be analyzed and reported. Useful information in such a report would include the key sources of uncertainty, expected value estimates of outcomes, the sensitivity of results to important sources of uncertainty, and where possible, the probability distributions of benefits, costs, and net benefits.
>
> a. **Characterizing uncertainty.** Analyses should attempt to characterize the sources of uncertainty. Ideally, probability distributions of potential benefits, costs, and net benefits should be presented. It should be recognized that many phenomena that are treated as deterministic or certain are, in fact, uncertain. In analyzing uncertain data, objective

> estimates of probabilities should be used whenever possible. Market data, such as private insurance payments or interest rate differentials, may be useful in identifying and estimating relevant risks. Stochastic simulation methods can be useful for analyzing such phenomena and developing insights into the relevant probability distributions. In any case, the basis for the probability distribution assumptions should be reported. Any limitations of the analysis because of uncertainty or biases surrounding data or assumptions should be discussed.
>
> b. **Expected values.** The expected values of the distributions of benefits, costs, and net benefits can be obtained by weighing each outcome by its probability of occurrence and then summing across all potential outcomes. If estimated benefits, costs, and net benefits are characterized by point estimates rather than as probability distributions, the expected value (an unbiased estimate) is the appropriate estimate for use. Estimates that differ from expected values (such as worst-case estimates) may be provided in addition to expected values, but the rationale for such estimates must be clearly presented. For any such estimate, the analysis should identify the nature and magnitude of any bias. For example, studies of past activities have documented tendencies for cost growth beyond initial expectations; analyses should consider whether past experience suggests that initial estimates of benefits or costs are optimistic.

Finally, in 1998, the OMB established the requirements for capital asset planning and budgeting to implement the Government Performance and Results Act of 1993 (GPRA) in OMB Circular No. A-11 (OMB, 1998), which states under the heading of "Risk Management":

> Risk management should be central to the planning, budgeting, and acquisition process. Failure to analyze and manage the inherent risk in all capital asset acquisitions may contribute to cost overruns, schedule shortfalls, and acquisitions that fail to perform as expected. For each major capital project, a risk analysis that includes how risks will be isolated, minimized, monitored, and controlled may help prevent these problems.
>
> The project cost, schedule and performance goals established through the planning phase of the project are the basis for approval to procure the asset and the basis for assessing risk.

Finding 3-11. Preproject planning is key to successful large endeavors. OMB Circulars A-94 and A-11 provide guidance for the planning of such projects, particularly with regard to schedules and risk analyses. A planning document of this nature was not provided to the committee.

Recommendation 3-11. PMCD should follow the requirements of OMB Circular A-94 and OMB Circular A-11 for capital projects performed by government agencies to improve the prospects for avoiding schedule overruns. Detailed preproject and project plans should be prepared and used as a basis for making important decisions.

4

Risk, Safety, and Stakeholder Issues

The criteria to be used by the Defense Acquisition Executive to evaluate the modified baseline design and other technologies being considered for Pueblo are spelled out in the NOI for Pueblo (PMCD, 2000):

> [The facility] would have to be determined to be as safe as and as cost efficient as baseline incineration. It must also be capable of completing destruction of the Pueblo Chemical Depot stockpile by the later of the Chemical Weapons Convention destruction date or the date the [PCD] stockpile would be destroyed if baseline incineration was used.

The committee's evaluation of the modified baseline process in Chapter 3 is based on these criteria. Chapter 4 covers safety and risk factors and assesses the Army's interactions with stakeholders concerning the Pueblo site.

SAFETY AND RISK CONSIDERATIONS

The chief components of a safety and risk evaluation are a quantitative risk assessment (QRA), a health risk assessment (HRA), and hazard evaluations (U.S. Army, 1997). The QRA process is conducted in two phases. A Phase 1 QRA is completed prior to facility construction as a component of the EIS. A Phase 1 QRA provides only a point estimate (an assessment without consideration of uncertainty) of public risk from accidental releases of agent. A Phase 2 QRA, which is based on the constructed plant facilities and operations, assesses both public and worker risk from accidental releases and plant upsets. The HRA, which is typically prepared by the Army as part of the RCRA permitting process, considers routine emissions and off-normal operations and assesses all possible human health risks at the site deriving from releases of agent, other emissions, or operating procedures. The HRA and QRAs are complementary in that the former considers normal and off-normal operations and the latter consider accident and upset conditions. Hazard evaluations are detailed assessments of specific operating hazards (including mitigation procedures derived from the QRAs) and are used for managing plant operations safely.

The Army contends that the modified baseline process will be simpler and safer to operate than the baseline system because, among other things, the process will be confined to a one-story building; the LIC furnace and its associated agent drain system and PFS/PAS will not be there; control instrumentation and heating, ventilation, and air conditioning systems should accordingly be less complex; and the DFS, if required, would be located in a separate structure. For the modified baseline process, there will be a requirement for a special accessing procedure (punching), freezing equipment and associated conveyers and holding space, and disposal of spent decontamination solution in the MPF afterburner. Until additional analyses associated with the Phase 1 quantitative risk assessment and the health risk assessment are completed, there are insufficient data by which to quantify the safety of the modified baseline process relative to the baseline system.

Phase 1 QRA for a Baseline System at Pueblo

A site-specific Phase 1 QRA for a baseline incineration system at Pueblo was prepared and published in 1998 (SAIC, 1998). The causes of potential accidents considered included failures of equipment, human error, and external phenomena such as earthquakes and airplane crashes. Intentional acts, such as sabotage, were not included, nor were nonagent health risks (which will be covered in the HRA). The Phase 1 QRA concluded that the probability of one or more public fatalities from operation of the baseline system is very much lower than the risk of storing the stockpile for 20 years. However, the probability of fatalities at Pueblo under either scenario was estimated to be very much lower than at the other baseline sites (Table 4-1).

As Table 4-1 shows, it is much less risky to destroy the stockpiled agents at these sites than to continue storing them. The table also shows that a baseline facility at Pueblo has the

TABLE 4-1 Summary of Results of Phase 1 QRAs for Baseline Incineration Systems at Several Sites

Site	Probability of One or More Public Fatalities During Disposal Operations	Probability of One or More Public Fatalities in 20 Years of Continued Storage
Pine Bluff, Arkansas	1 in 20,000	1 in 33
Blue Grass, Kentucky	1 in 83,000	1 in 64
Umatilla, Oregon	1 in 300,000	1 in 400
Anniston, Alabama	1 in 435,000	1 in 100
Pueblo, Colorado	Less than 1 in 1,000,000,000	1 in 1,000,000

Source: Adapted from SAIC, 1998.

lowest risk among the sites listed because the PCD inventory is entirely mustard munitions, whereas other sites have significant stores of nerve agents. Mustard agents are much less volatile and less toxic than nerve agents, so lethal doses are less likely to be widely dispersed in the event of an explosive disruption. However, because mustard agent is carcinogenic, the Phase 1 QRA included the estimated risk of a cancer fatality from exposure. The risk was found to be extremely low—less than a one in a million chance for one cancer fatality during continued storage or less than a one in a billion chance during processing. The highest risks in the Phase 1 QRA for Pueblo are from external events such as an earthquake or an airplane crash.

Other Risk Assessments

A number of studies have been initiated to establish a basis for comparing the risks from a baseline system facility at Pueblo with proposed alternatives (including the modified baseline process) (U.S. Army, 2001b). These studies include risk assessments on (1) the transportation of materials into and out of the PCD; (2) the risks of MAVs versus ONCs; (3) a comparison of a ground-floor storage and unpack area for a modified baseline process with the two-story, ONC-dependent configuration used in the baseline system; and (4) an estimate of the number of leaking projectiles. Additional studies that are planned but have not yet been initiated include (1) the risk analysis for the processing of frozen, undrained munitions in the MPF; (2) the Phase 2 QRA; (3) the HRA; and (4) supporting analyses of safety and hazardous operations.

All these assessments will provide information for comparing the risks associated with the modified baseline process with those associated with other alternatives. The Stockpile Committee previously recommended that the primary criterion for the selection of technology should be the “minimization of cumulative adverse consequences from all relevant risks” (NRC, 1994). Cumulative risks include risks to the public and workers, as well as the economic and schedule risk measures provided in the NOI for Pueblo (PMCD, 2000).

Baseline system operations at Pueblo are estimated to present an extremely small risk to the public—in fact, a much smaller risk than at any other continental U.S. stockpile site. Because the estimated risk with the baseline system is so small, the Army must carefully consider the challenges of attempting to develop a modified process. A modified baseline process, whatever its final configuration, is expected to present a negligible risk to workers and the public, at least in theory. An uncertainty, however, is the behavior of frozen agent-containing munitions introduced to the MPF, which has never been tested. The possibility of plugging of the accessed agent cavity, which could lead to an expulsion of either liquid or solid agent and a consequent spike in the MPF temperature, must be tested and evaluated.

Results of the Phase 1 QRA suggest that the risk to the public from operation and storage at Pueblo is very small. Therefore, a framework for comparison for Pueblo might include an agreement that risks associated with alternative designs of the modified baseline process be considered equivalent if they are confidently below a specified (and small) reference value. This kind of framework would remove the potential for eliminating some viable, low-risk technologies from consideration because of an insignificant difference. Similar risk comparisons must be made for all risks, not just the public risk calculated in the Phase 1 Pueblo QRA. Until a Phase 2 QRA is completed, risk attributes of the baseline system configuration for Pueblo cannot be determined. Based on the values in Table 4-1, the framework described above would probably be applicable only to the Pueblo site.

The discussion and development of the framework for risk comparisons must involve community stakeholders. The Pueblo city and county government and many members of the community are anxious for demilitarization activities to be completed as soon as possible in a way that ensures the safety of all concerned. Although some redevelopment on the PCD site has already begun, full commercial development of the site cannot begin until demilitarization of the PCD stockpile is completed.

Finding 4-1. A Phase 1 QRA for using a baseline incineration system at Pueblo has been completed, and the point estimation of the impact on public health indicates that the risk to the public due to accidental releases would be extremely low. The HRA for Pueblo has not yet been completed. Several additional analyses are being conducted to support operational and design decisions for a modified baseline process. It is not clear how the Army is going to use the collective risk information it has or is seeking and in what framework this information will be used.

Recommendation 4-1. Before the HRA is completed, the Army should work closely with all stakeholders to decide how the risk of a modified baseline process will be compared with the risk of the baseline incineration system. Such a framework should ensure fair comparison of both configurations as a basis for deciding on the acceptability of the modified baseline process.

Finding 4-2. One specific criterion for evaluating the modified baseline design, as documented in the NEPA notice of intent for Pueblo, is that the facility be "as safe as" baseline incineration. Because of the very low risk at Pueblo, it is not clear how this and other criteria can be implemented.

Recommendation 4-2. The Army should expedite obtaining necessary risk information so interested parties can compare the baseline incineration system and the modified baseline process. An important step for ensuring that the necessary risk information is obtained in a timely manner is the establishment of a comprehensive risk management framework. Such a framework would clearly identify the risk measures of interest and reflect the criteria specified in Public Law 105-261 and the NEPA NOI concerning a disposal facility for the Pueblo stockpile.

WORKER SAFETY AND TRAINING

The modified baseline process is considerably simpler than the baseline system. The optimal modified configuration involves using only one furnace (the MPF) at any time, whereas as many as four different furnaces can be used at one time in the baseline system.[1] If only one furnace is operated, a much less complex control system will be required than for the baseline system. Furthermore (as discussed in Chapter 3), the use of an agent/munition freezing operation may greatly reduce maintenance requirements, resulting in fewer entries by personnel in DPE suits and, thus, fewer opportunities for hazardous exposure. At this time, the committee cannot evaluate the potential risk of introducing frozen munitions to the MPF, because, to the committee's knowledge, this operation has never been tested. Two other features of the modified baseline process could also increase risk: (1) more agent would be in the MPF at any one time than there was during disposal operations at JACADS and (2) the carbon filters used in the PAS may require replacement over the course of disposal operations, contributing an added source of worker risk. Carbon filters are also being installed at the Anniston, Umatilla, and Pine Bluff facilities, but they were not used at JACADS or TOCDF.

On a qualitative basis, it appears that worker risk in the modified baseline process will be as low as or lower than risk in the baseline system. Quantitative estimates of risk will be provided in the HRA and various hazard evaluations. The committee has stated several times that safety must be the foremost objective in any demilitarization operation involving chemical agent, including operations at PUCDF (NRC, 1996, 1997). Safety should be weighted higher than production rate or cost control.

Training requirements for process workers will essentially be the same for the modified baseline process as for the baseline system. General Physics, the systems contractor for training PUCDF workers, operates the Chemical Demilitarization Training Facility in Edgewood, Maryland, for all CSDP and contractor workers (U.S. Army, 2000c). Initial training takes place in Edgewood, and a simulator for PUCDF operators that will be installed will also be available for ongoing training. Separate training is provided for ammunition handlers and maintenance personnel. A self-paced curriculum is being developed to provide refresher training to control room operators.

Finding 4-3. The modified baseline process as currently configured may be simpler than the baseline incineration system. It may possibly be safer if new operations, such as the processing of frozen munitions, are found not to increase risk.

Recommendation 4-3. Safety should be given the highest priority during the construction, systemization, operation, and closure of the Pueblo Chemical Agent Disposal Facility, regardless of the technology configuration.

STAKEHOLDER CONTACTS

Part of the committee's statement of task for this report (cited in Chapter 1) is to receive briefings from stakeholders in addition to PMCD project personnel and NEPA document preparers. These briefings were expected to augment the information received from PMCD sources and to enable the committee to put the latter information into perspective. The Stockpile Committee has consistently advised the Army on the importance of providing appropriate opportunities for meaningful public involvement in decision making concerning the CSDP, most recently in *A Review of the Army's Public Affairs Efforts in Support of the Chemical Stockpile Disposal Program* (NRC, 2000).

Stakeholders that provided input for this study were the PCD, the Chemical Stockpile Emergency Preparedness Program (CSEPP), the Colorado Department of Public Health and Environment (DPHE), the Working Integrated Project Team, the Colorado Citizens Advisory Commission (CAC), and, most importantly, people who live in Pueblo.

Pueblo Chemical Depot

PCD is commanded by an active-duty Army lieutenant colonel, who is assisted by a staff of about 150 civilian employees, one of the most active and effective members of

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[1] In the baseline incineration system, separate furnaces are provided for liquid agent, metal parts, energetic materials, and dunnage (packing materials). Certain designs have more than one furnace for liquid agent. If dunnage can be disposed of off site, however, the dunnage furnace is not used.

which is the public affairs officer. PCD's strategic priorities at present are to (Megnia, 2000):

- store the chemical weapons safely and securely
- sustain base operations
- remediate several environmental hazards arising from operations at the PCD since it was established in 1942
- destroy the weapons and residues
- transfer the property and facilities to the reuse authority and close the base

The committee believes that good progress on all of these is being made. There have been no major storage disruptions at the base and only two leakage incidents, one in 1997 and one late in 2000. In both instances, PCD took prompt, effective action to contain them, and no detectable agent was released to the atmosphere outside the affected igloo.

Judging from site visits by committee members, the base appeared to be adequately maintained. Two major remediation projects are proceeding. One is to purge volatile organic compounds (mostly trichloroethylene) from the water table to prevent an underground plume from spreading and contaminating the water supply of Avondale, a nearby community. The other is to clean up explosive residues (including unexploded ordnance) that underlie some areas of the base. Very recently, TNT decomposition products have been identified in the Avondale water supply, and a remediation order from the Colorado DPHE is expected soon.

The PCD commander believes he has good working relations with PMCD, regulators, county government, CSEPP, and the local community. He is willing to work cooperatively on whatever plans evolve.

Construction beginning in 2001 has been approved for infrastructure (steam, electric power, natural gas utility service, and roads) that will be necessary for any of the disposal technologies being considered, with a budget of about $10 million. Plans have been completed for the evacuation of base personnel in the event of an agent release or other disaster, although one road on the base must still be connected to a nearby public road to increase current evacuation routes. A fairly detailed plan for transferring facilities to the Pueblo Development Authority has already been put into effect. Some facilities have already been turned over to the PDA and are on lease to several tenants. The PDA was concerned about the proposed location of the electric power substation and has proposed building and owning the substation to ensure its preferred location. PMCD and the U.S. Army Corps of Engineers have indicated that the substation should be closer to the PUCDF to minimize line losses and to comply with PMCD policies for electric power transmission to chemical agent disposal facilities. The disagreement caused some delay in implementation of the substation project. It was also noted that construction of the personnel support building will be delayed beyond 2001 because of the need to substantially increase the size of the facility.

Emergency Management Plans

The Chemical Stockpile Emergency Preparedness Program (CSEPP) for the Pueblo site is housed in a modern control center in Pueblo County facilities that are shared with other county emergency preparedness units. All emergency preparedness units, including CSEPP, report to the county emergency management coordinator (EMC). The heads of both these groups told committee representatives that, except for completing two projects, CSEPP is ready to deal with any emergency at PUCDF. Evacuation routes from the Transportation Research Center immediately north of PCD and from the industrial park at the Pueblo airport still require increased capacity. Also, the installation of 850 indoor tone-alert radios in residences and businesses in the potentially affected area must be completed. Full-scale emergency drills are held periodically, and relations with PCD are good. CSEPP is funded by the Federal Emergency Management Agency with funds provided by DoD.

Colorado Department of Public Health and Environment and the Working Integrated Project Team Process

The Colorado DPHE federal facilities program manager and another staff member met with committee representatives in September 2000. The office of the federal facilities program manager regulates various cleanup efforts at PCD and is the chief environmental regulator involved in the PUCDF project. Interaction with the PUCDF project occurs through participation in an environmental working integrated project team (WIPT); other members include the Pueblo County Commissioner's Office, EPA, PCD, the Army Soldier Biological Chemical Command, the U.S. Army Corps of Engineers, PMCD, the Program Manager for Assembled Chemical Weapons Assessment (PMACWA), and their contractors.

The goal of the WIPT is to identify and solve problems at an early stage, thus expediting the regulatory activities of the PUCDF project (e.g., approving the infrastructure construction projects) (WIPT, 2000a, 2000b, 2000c). The DPHE manager believes the WIPT process is working fairly well. Initial WIPT meetings in Denver and in Edgewood, Maryland, were not open to the public, but the WIPT meeting in Pueblo on December 6, 2000, was open to the public. Some concerned citizens were present, although public attendance was much smaller than meeting sponsors had expected. Also, the relationship between the DHPE and PMACWA staff appeared to be well established.

A second WIPT, the "Acquisition WIPT," was set up to provide a single government interface with the contractors and the public throughout the acquisition phase (the design and construction of PUCDF). Members will include PCD, PMCD, PMACWA, the U.S. Army Corps of Engineers, Operations Support Command, and contracting personnel (WIPT, 2000a, 2000b, 2000c; U.S. Army, 2000b).

Citizens Advisory Commission

The CAC "provides a vital link between the Pueblo community and the Army by providing a forum for exchanging information about chemical weapons disposal. It exists to represent community interests" (U.S. Army, 2000e). The nine CAC members are appointed by and serve terms at the governor's discretion. They include local business people and citizens, a labor leader, an environmentalist, and a representative of Colorado DPHE; a county commissioner presides. The CAC is funded by DoD but is "independent of Army influence" (U.S. Army, 2000e).

At meetings in September and December 2000 attended by members of the Stockpile Committee and PMCD and PMACWA representatives and their contractors attempted to explain the technologies under consideration in the EIS process for the Pueblo site. The technologies and the EIS process are very complex, and some CAC members and members of the audience appeared to be somewhat confused. Personnel associated with the PUCDF project had some difficulty describing clearly the features of the designs and justifications for them, as well as putting levels of risk in perspective. The following concerns were expressed by CAC members about the modified baseline process:

- the multiple handling of munitions if enhanced reconfiguration were employed (this issue was resolved by the PMCD decision to abandon the enhanced reconfiguration for the modified baseline process)
- the ability of the modified baseline process to prevent the release of mercury in gas emissions
- the shipping of energetics for off-site treatment
- the reasons for accelerating the NEPA EIS decision process

Additional meetings are planned to ensure that CAC members understand the technology options. The CAC did not take a position on a choice of technology, but in October 1999, had voted 4–3 (1 abstention, with eight of nine members present) in favor of continuing to pursue the ACWA alternatives. At that time, the county commissioners and city council members indicated a preference for incineration (U.S. Army, 2000b). At the September 2000 CAC meeting, attended by several Stockpile Committee members, five citizens in the audience expressed strong feelings in favor of ACWA alternatives and against incineration. They also expressed dissatisfaction that they were excluded from the WIPT process. Whether others in the community or the CAC agreed or not was not evident, and no one spoke in favor of the incineration option.

A 1999 survey of 1,068 randomly chosen Pueblo County residents revealed that a majority favored incineration over the alternatives (Williams et al., 1999). This conclusion was reconfirmed in a follow-up survey after TOCDF experienced a small release of agent in May 2000.

Evaluation of Pueblo Stakeholder Relations

Based on the committee's limited contacts, no firm conclusions could be drawn about stakeholder relations. It was evident from comments made at the CAC meetings, however, that the CAC members respect the PCD commander and the depot public affairs officer and were satisfied with PCD operations. It was also evident that some members of the CAC and the public may not understand the merits of the technology alternatives and the risks they may entail.

The CSEPP appears to have emergency management activities under control and to enjoy the trust and respect of Pueblo County officials. CSEPP personnel recognize that more needs to be done to develop evacuation routes and procedures and to complete the distribution of early warning radios.

The WIPT process appears to be reasonably effective and is attempting to work through regulatory issues as they emerge. The process has been viewed with suspicion by some stakeholders, but opening WIPT meetings to the public may allay such suspicions.

Although the PCD commander and staff, along with PMCD, generally enjoy good relations with the Pueblo community, there are apparent communication difficulties that have resulted in lingering confusion about the future. Some misunderstandings seem to have arisen about what would comprise a pilot-scale facility and when it might be installed and tested. The NOI alternatives listed in the NOI published in April 2000 as part of the NEPA process are:

> a. A baseline incineration facility,
> b. A full-scale facility to pilot test the single-story incineration process,
> c. A full-scale facility to pilot test the alternative technology successfully demonstrated by the Assembled Chemical Weapons Assessment Program—neutralization followed by supercritical water oxidation,
> d. A full-scale facility to pilot test the alternative technology successfully demonstrated by the Assembled Chemical Weapons Assessment Program—neutralization followed by biodegradation,
> e. No action, an alternative which will continue the storage of the mustard agent and munitions at Pueblo Chemical Depot.

Some community leaders apparently believe that installation of a small-scale pilot test of one or more of the ACWA alternatives was promised. However, the wording of the NOI implies that, for at least three options, the choice was a "full-scale facility to pilot test."

Finally, concerns have also been expressed by some community members about the safe disposal of condensed heavy metal vapor from incineration-based processes and options for energetics disposal.

Finding 4-4. Some community leaders perceive that the office of the Program Manager for Chemical Demilitarization has not been adequately responsive and forthcoming regarding information requests from concerned citizens and CAC members. Presentations to the public describing the modified baseline process have not been as clear or informative as possible.

Recommendation 4-4. The Army should make a greater effort to educate the public about possible disposal processes, as well as the relative risk of continued stockpile storage versus disposal. Army officials responsible for the Chemical Stockpile Disposal Program, in close coordination with the commander of the Pueblo Chemical Depot and other local Army representatives, should strive to maintain and improve open communications with the public, the Citizens Advisory Commission, and interest groups. *A Review of the Army's Public Affairs Efforts in Support of the Chemical Stockpile Disposal Program* may be used for guidance. The Army should be particularly responsive to questions and requests for information from local officials and other stakeholders, taking every opportunity to discuss the Chemical Stockpile Disposal Program with the public. All presentations for the public and other stakeholders must be targeted, clear, and of a high professional caliber.

5

Findings and Recommendations

The findings and recommendations presented in Chapters 2–4 are assembled below and numbered in accordance with the chapter in which they appear.

Finding 2-1. Trial burn results from the 1999 JACADS tests confirmed the required destruction and removal efficiency of 99.9999 percent when 4.2-inch mortar projectiles filled with mustard agent were incinerated through the metal parts furnace at a feed rate of 96 rounds per batch. Subsequently, almost 95,000 mustard projectiles were successfully destroyed in the JACADS MPF by mid-1999.

Recommendation 2-1. Based on the successful JACADS campaigns, the Army should evaluate a process design for Pueblo in which the munitions filled with mustard are processed through an MPF.

Finding 2-2. The 1999 JACADS trial burn did not include introduction of frozen projectiles into the metal parts furnace for final processing. Mustard in the frozen projectiles thawed before entering the MPF.

Recommendation 2-2. The Army should determine whether freezing projectiles before opening the mustard agent cavity to the atmosphere is necessary to mitigate frothing. If so, the Army should determine, by testing, whether frozen projectiles can be processed successfully through a metal parts furnace, or as an alternative, if it is feasible to allow the agent to thaw before the projectiles are fed to a metal parts furnace.

Finding 2-3. HT mustard-filled munitions were not processed at JACADS. HT and HD consist of similar chemicals and will most probably result in much the same products of combustion. Nevertheless, there is no evidence that testing and analysis of HT combustion have taken place.

Recommendation 2-3. Regarding HT, the Army should verify that the combustion of HT will produce results akin to the combustion of HD. These results should be considered in the development of the modified baseline process.

Finding 2-4. The 1999 JACADS trial burn results indicated that mercury and cadmium were emitted at unacceptable levels during the disposal of some mustard agent.

Recommendation 2-4. The Army should prove, through testing, an acceptable technique for capturing emissions of heavy metals—particularly cadmium and mercury—from the metal parts furnace when processing mustard-filled projectiles. An acceptable disposal plan for accumulated heavy metals must be included in the modified baseline process or any other process.

Finding 2-5. Secondary wastes, including dunnage and demilitarization protective ensemble suits, were reported to be successfully processed through the metal parts furnace (MPF) at JACADS, but only limited data on rates, operating conditions, and other parameters for handling these wastes in the MPF have been presented. The best way to handle spent carbon appears to be through the use of a micronizer system**.**

Recommendation 2-5. The Army should determine whether adequate data are available from JACADS to support the efficacy of processing secondary wastes in the metal parts furnace. If not, the Army should determine the additional tests required to confirm a disposal process. A plan based on these results should also be developed for handling and disposing of all secondary wastes from processing the Pueblo stockpile, including demilitarization protective ensemble suits and hoses, spent carbon filter materials, scrubber brine solutions, plant cleaning wastes, and dunnage.

Finding 3-1. The Army has not determined when a commitment to an on-site deactivation furnace system as part of a modified baseline process at Pueblo must be made if a permit for the off-site transport of energetics has not been received.

Recommendation 3-1. The Army should develop a process and schedule to determine when a decision must be made between the off-site transport of energetics or their on-site disposal in a deactivation furnace system. To avoid schedule delays, the decision mechanism must account for uncertainties in the permitting process.

Finding 3-2. If the Army intends to use the freezing process at Pueblo, data on the behavior of frozen rounds will be essential to confirm the feasibility of a modified baseline process that integrates freezing of the munitions for agent accessing prior to their treatment in the metal parts furnace.

Recommendation 3-2. The Army should obtain experimental data on the behavior of frozen mustard rounds fed into the metal parts furnace (MPF). At a minimum, these data should demonstrate that:

- Frozen rounds (HD and HT) can be processed in the MPF without adverse consequences from the simultaneous presence of agent in solid, liquid, and gas phases, which might lead to spiking of furnace temperatures and pressures from agent confinement and rapid subsequent release in the gaseous phase.
- Complete volatilization and destruction of the frozen agent in the MPF can be achieved.
- Solid agent will not be ejected and propelled against internal surfaces of the MPF.
- Temperatures and residence times necessary to achieve destruction have been determined.

Finding 3-3. The committee could not determine whether an experimental program to verify the feasibility of processing frozen mustard rounds in the metal parts furnace would delay the disposal schedule for the Pueblo Chemical Agent Disposal Facility. However, the need for experimental verification is not only a technical consideration, but also a regulatory issue. Although the committee did not evaluate the regulatory climate at Pueblo concerning this issue, obtaining a permit for a one-of-a-kind modified baseline process may be more difficult and more time consuming than obtaining a permit for the baseline system, which has been successfully demonstrated at two facilities and supported with extensive trial burn data.

Recommendation 3-3a. The Army should evaluate the risk of delay in obtaining a permit for the proposed modified baseline process at Pueblo that includes the treatment of frozen mustard rounds in the metal parts furnace (MPF). The evaluation should take into account the permitting experience for the process used at JACADS to freeze 201 mustard rounds and feed partially thawed 100-percent-filled mustard agent rounds into the MPF.

Recommendation 3-3b. The Army should evaluate the efficacy of allowing frozen munitions to thaw before feeding them into the metal parts furnace of a modified baseline process in a manner similar to the procedure used at JACADS. If the Army intends to include this process step, associated safety, design, maintenance, and regulatory approval issues should be assessed.

Finding 3-4. The machines proposed for accessing agent in the modified baseline process differ from the multipurpose demilitarization machines used for this purpose at JACADS. The method proposed for accessing mustard agent should open the munition cavity sufficiently to enable complete destruction of the agent in the metal parts furnace.

Recommendation 3-4a. The Army should demonstrate that the method selected for accessing mustard agent opens the munition agent cavity sufficiently to enable complete destruction of the agent in the metal parts furnace.

Recommendation 3-4b. If the development and testing of the machines for accessing agent in the modified baseline process would delay disposal operations past the Chemical Weapons Convention deadline, the Army should consider installing another technology at Pueblo.

Finding 3-5. Freezing mustard munitions to avoid problems with foaming/frothing of agent is not currently planned for any of the baseline facilities in the continental United States.

Recommendation 3-5. The Army should determine whether the method proposed for capturing mustard agent during agent accessing at baseline system facilities could be adapted for use at Pueblo with a potential savings over the cost of developing and testing freezing methods.

Finding 3-6. Continuous throughput and safe operation of the metal parts furnace are the most critical aspects of the proposed modified baseline process for Pueblo. The furnace can be sized to operate safely and reliably with substantial loading.

Recommendation 3-6. A modified baseline process at Pueblo should include a four-zone (rather than three-zone) metal parts furnace with design provisions to ensure safe shutdown and restarting in the event of operational upsets, such as a loss of electrical power, combustion air supply, or exhaust gas capability.

Finding 3-7. The control of emissions of cadmium and mercury by the PFS HEPA and carbon filters has yet to be demonstrated. The PFS filters will be tested during systemization at Anniston Chemical Agent Disposal Facility.

Recommendation 3-7. Tests and analyses for the control of metal emissions, especially cadmium and mercury (elemental and total) and organics (products of incomplete combustion), should be conducted for the metal parts furnace and afterburner and PAS/PFS prior to completion of the design for the modified baseline process to ensure that emissions are within required limits. Necessary control technologies should be incorporated into the plant design.

Finding 3-8. Secondary wastes, which include contaminated dunnage, DPE suits, spent decontamination solution, and contaminated spent carbon, were treated at JACADS using a combination of furnaces and afterburners, or a micronizer and a burner system for spent carbon. Uncontaminated dunnage and spent carbon, slag, and ash were shipped off site to permitted waste disposal facilities after being tested to ensure they were suitable for shipment.

Recommendation 3-8. Lessons learned at JACADS from the disposal or decontamination of demilitarization protective ensemble suits and dunnage in the metal parts furnace should be incorporated into the design and operation of the comparable furnace (MPF) of the modified baseline process. Spent decontamination fluid should be injected into the MPF afterburner (or deactivation furnace system [DFS] afterburner) if it cannot be shipped off site. Similarly, contaminated spent carbon can be processed through either the MPF or the DFS if there is one. Uncontaminated dunnage and spent carbon, slag, and ash can be shipped off site to permitted waste disposal facilities after being tested to ensure they meet all requirements for off-site disposal.

Finding 3-9. Monitoring systems currently used at existing baseline system facilities appear to be adequate for use in a modified baseline process at Pueblo. The addition of a third, standby automatic continuous air monitoring system unit in the area of the metal parts furnace (MPF) is a reasonable modification in light of the increase in agent throughput over the throughput for the MPF of the baseline system. Notwithstanding the current lack of regulatory requirements for continuous monitoring, further development of monitors for metals and organics is likely to be beneficial for confirming clean emissions. This would also support the Army's interaction with local citizens by making definitive emissions data more available to the public.

Recommendation 3-9. The Army should evaluate state-of-the-art analytical tools for continuous monitoring of emissions of metals, dioxins, and products of incomplete combustion. If they are effective, the Army could install them at chemical agent disposal facilities where applicable. If continuous monitors are not effective, the Army could conduct stack tests for dioxins/furans, mercury, and organics at suitable intervals to provide some additional assurance to the surrounding communities that the modified baseline process is working properly.

Finding 3-10. Although the modified baseline concept is derived from the lessons learned at JACADS, no closure plan has been developed. The committee found no evidence of explicit considerations of closure in the design or design criteria of the modified baseline process for the PUCDF.

Recommendation 3-10. Engineering, design, and construction plans for the Pueblo Chemical Agent Disposal Facility should incorporate all of the requirements for closure identified at JACADS and other baseline system facilities. Value-engineering studies should be initiated to review all existing designs for conformance to closure principles identified in the forthcoming NRC report on the closure of JACADS. The Army should also initiate closure planning as soon as possible.

Finding 3-11. Preproject planning is key to successful large endeavors. OMB Circulars A-94 and A-11 provide guidance for the planning of such projects, particularly with regard to schedules and risk analyses. A planning document of this nature was not provided to the committee.

Recommendation 3-11. PMCD should follow the requirements of OMB Circular A-94 and OMB Circular A-11 for capital projects performed by government agencies to improve the prospects for avoiding schedule overruns. Detailed preproject and project plans should be prepared and used as a basis for making important decisions.

Finding 4-1. A Phase 1 QRA for using a baseline incineration system at Pueblo has been completed, and the point estimation of the impact on public health indicates that the risk to the public due to accidental releases would be extremely low. The HRA for Pueblo has not yet been completed. Several additional analyses are being conducted to support operational and design decisions for a modified baseline process. It is not clear how the Army is going to use the collective risk information it has or is seeking and in what framework this information will be used.

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Recommendation 4-2. The Army should expedite obtaining necessary risk information so interested parties can compare the baseline incineration system and the modified baseline process. An important step for ensuring that the necessary risk information is obtained in a timely manner is the establishment of a comprehensive risk management framework. Such a framework would clearly identify the risk measures of interest and reflect the criteria specified in Public Law 105-261 and the NEPA NOI concerning a disposal facility for the Pueblo stockpile.

Finding 4-3. The modified baseline process as currently configured may be simpler than the baseline incineration system. It may possibly be safer if new operations, such as the processing of frozen munitions, are found not to increase risk.

Recommendation 4-3. Safety should be given the highest priority during the construction, systemization, operation, and closure of the Pueblo Chemical Agent Disposal Facility, regardless of the technology configuration.

Finding 4-4. Some community leaders perceive that the office of the Program Manager for Chemical Demilitarization has not been adequately responsive and forthcoming regarding information requests from concerned citizens and CAC members. Presentations to the public describing the modified baseline process have not been as clear or informative as possible.

Recommendation 4-4. The Army should make a greater effort to educate the public about possible disposal processes, as well as the relative risk of continued stockpile storage versus disposal. Army officials responsible for the Chemical Stockpile Disposal Program, in close coordination with the commander of the Pueblo Chemical Depot and other local Army representatives, should strive to maintain and improve open communications with the public, the Citizens Advisory Commission, and interest groups. *A Review of the Army's Public Affairs Efforts in Support of the Chemical Stockpile Disposal Program* may be used for guidance. The Army should be particularly responsive to questions and requests for information from local officials and other stakeholders, taking every opportunity to discuss the Chemical Stockpile Disposal Program with the public. All presentations for the public and other stakeholders must be targeted, clear, and of a high professional caliber.

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Appendixes

Appendix A

Description of Pueblo Chemical Depot Stockpile

The entire inventory of munitions at the PCD contains mustard agent. Most projectiles contain agent HD, which is distilled β,β′-dichloroethyl sulfide. Some contain HT, a 60:40 eutectic mixture of HD and bis[2-(2-chloroethylthio)-ethyl] ether. All munitions may contain manufacturing by-products or impurities, degradation products, and inorganic residues.

Table A-1 lists the kinds and numbers of munitions in the Pueblo stockpile.

Figures A-1, A-2, and A-3 are cutaway drawings of the 105-mm shell, 155-mm shell, and 4.2-inch mortar projectile, respectively.

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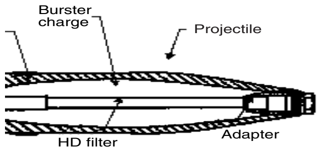
TABLE A-1 Pueblo Chemical Depot Munitions

Item	Quantity	Description
105-mm cartridge, M60, HD	28,375	Complete round in field cartridge case with propellant
105-mm rounds, M60, HD	355,043	Bursters only, with dummy plug
155-mm rounds, M104, HD	33,062	Bursters only, with lifting plug
155-mm rounds, M110, HD	266,492	Bursters only, with lifting plug
4.2-inch mortars, HT, M2	20,384	Fuze, burster, and tail assembly
4.2-inch mortars, HD, M2A1	76,722	Fuze, burster, and tail assembly

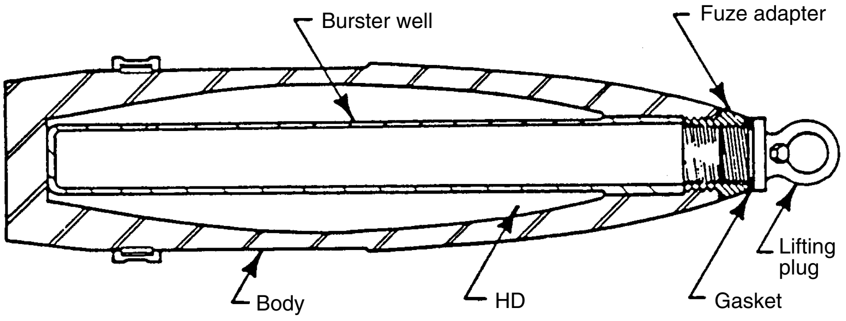
SOURCE: Adapted from U.S. Army 1997.



M60 Cartridge, 105-mm Howitzer

Length	31.1 inches	Booster	M22
Diameter	105 mm	Explosive	Tetrytol
Total weight	42.92 lb	Explosive weight	0.3 lb
Agent	HD	Propellant	M67
Agent weight	2.97 lb	Propellant weight	2.83 lb
Fuze	M557/M51A5	Primer	M28A2/M28B2
Burster	M5	Packaging	1 round/fiber container, 2 container/wooden box

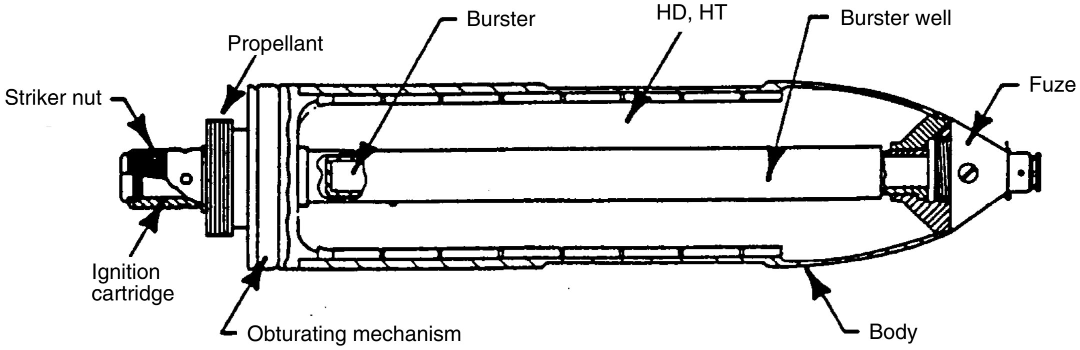
FIGURE A-1 105-mm howitzer projectile. NOTE: M60 105-mm cartridges have been reconfigured and therefore will not have propellant attached. SOURCE: Adapted from U.S. Army, 1977.



M110 Projectile, 155-mm Howitzer

Length	31.1 inches	Booster	M22
Diameter	155 mm	Explosive weight	0.41 lb
Total weight	94.6 lb	Propellant	None
Agent	HD	Propellant weight	None
Agent weight	11.7 lb	Primer	None
Fuze	None	Packaging	8 rounds/wooden pallet
Burster	M6		

FIGURE A-2 155-mm howitzer projectile. SOURCE: Adapted from U.S. Army, 1977.



Cartridge, 4.2-inch Cartridge/Mortar

	M2/HT	M2A1/HD
Length	21.0 inches	21.0 inches
Diameter	4.2 inches	4.2 inches
Total weight	24.67 lb	24.67 lb
Agent	HT	HD
Agent weight	5.8 lb	6.0 lb
Fuze	M8	M8
Burster	M14	M14
Explosive	Tetryl	Tetryl
Explosive weight	0.14 lb	0.14 lb
Propellant	M6	M6
Propellant weight	0.6 lb	0.4 lb
Primer	M2	M2
Packaging	1 round/fiber container, 2 containers/wooden box	1 round/fiber container, 2 containers/wooden box

FIGURE A-3 4.2-inch mortar cartridge. NOTE: 4.2-inch cartridges/mortars will be reconfigured as projectiles. Most 4.2-inch cartridges will also be defuzed. SOURCE: Adapted from U.S. Army, 1977.

Appendix B

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, April 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)

Occupational Health and Workplace Monitoring at Chemical Agent Disposal Facilities (June 2001)

Appendix C

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 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; process engineering; and 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. During 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 Neurology and Strokes 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.

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, and 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.

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 4 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 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 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 Massachusetts Institute of Technology 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 Massachusetts Institute of Technology 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 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 (MIT) with a B.S. in chemistry and from Harvard University with a Ph.D. in physical chemistry. He is currently 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 through stakeholder involvement.

Chadwick A. Tolman received his Ph.D. in physical chemistry from the University of California at Berkeley and until recently was a program officer in the organic and macromolecular chemistry program in the Division of Chemistry of the National Science Foundation. He is now a staff officer for the National Research Council Board on Environmental Studies and Toxicology. 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.