Disposal of Chemical Munitions and Agents (1984)

Pages
239

Size
8.5 x 11

ISBN
0309035279

Committee on Demilitarizing Chemical Munitions and Agents; Board on Army Science and Technology; Commission on Engineering and Technical Systems; National Research Council

1101290 AD-A148 584/6/XAB 84-0142

Disposal of Chemical Munitions and Agents

National Research Council, Washington, DC. Committee on Demilitarizing Chemical Munitions and Agents.

Corp. Source Codes: 019026010; 415266

1984 234p

Languages: English

NTIS Prices: PC A11/MF A01 Journal Announcement: GRAI8506

Country of Publication: United States

Contract No.: DAAG29-82-C-0012

For more than half a century, the United States has maintained a stockpile of highly toxic chemical agents and munitions for possible use in a wartime situation. The United States maintains its stockpile principally to deter other countries from using such munitions against U.S. forces. Four basic chemicals are kept. These are the nerve agents VX, which is persistent in its effects, and sarin (GB),* which is nonpersistent; the mustard agents H, HD, and HT, which are usually referred to simply as H; and the hallucinogenic agent BZ. These chemical agents are stored at eight U.S. Army depots in the Continental United States as well as on Johnston Atoll in the Pacific Ocean. The latter depot was not a part of this study. Each depot varies in size, in the type and number of agents and munitions in storage, and in its proximity to off-site civilian populations. Moreover, the agents are kept in a variety of containers and munitions--rockets, land mines, artillery and mortar shells, bombs and spray tanks, and bulk containers.

Descriptors: *Chemical ordnance; *Chemical agents; *Disposal ; *Demilitarization; Toxic agents; Stockpiles; Storage; Army facilities; Supply depots; Management; GB agent; VX agent; Mustard agents; Hallucinogens; Containers; Army operations; Safety; Explosive ordnance disposal; Transportation; Waste disposal; Decontamination; Environmental protection

Identifiers: Chemical munitions; NTISDODXA

Section Headings: 15B (Military Sciences--Chemical, Biological, and Radiological Warfare); 19A (Ordnance--Ammunition, Explosives, and Pyrotechnics); 74D (Military Sciences--Chemical, Biological, and Radiological Warfare); 68C (Environmental Pollution and Control--Solid Wastes Pollution and Control); 79A (Ordnance--Ammunition, Explosives, and Pyrotechnics)

Disposal of Chemical Munitions and Agents

Disposal of Chemical Munitions and Agents

A Report Prepared by the
Committee on Demilitarizing Chemical Munitions and Agents
Board on Army Science and Technology
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1984

NATIONAL ACADEMY PRESS 2101 CONSTITUTION AVE., NW WASHINGTON, DC 24018

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This study was supported by contract DAAG 29-82-C-0012 between the National Academy of Sciences and the Department of the Army.

LIBRARY OF CONGRESS CATALOG CARD NUMBER 84-62500
INTERNATIONAL STANDARD BOOK NUMBER 0-309-03527-9

Printed in the United States of America

Committee on Demilitarizing Chemical Munitions and Agents

NORTON D. ZINDER *(Chairman)*, Professor of Genetics, Rockefeller University, New York, New York
ROBERT W. BUCHHEIM *(Technology Assessment Panel Chairman)*, formerly Deputy Assistant Director, U.S. Arms Control and Disarmament Agency, Phoenix, Arizona
HARRISON SHULL *(Stockpile Assessment Panel Chairman)*, Chancellor, University of Colorado, Boulder, Colorado
D. WARNER NORTH *(Stockpile Assessment Panel Assistant Chairman)*, President, Decision Focus, Inc., Los Altos, California
LEO G. ABOOD, Professor, University of Rochester Medical Center, Rochester, New York
CHARLES H. BEDINGFIELD, Principal Consultant, E. I. duPont de Nemours & Company (Retired), Newark, Delaware
AUSTIN W. BETTS, Consultant to the President, Southwest Research Institute, San Antonio, Texas
ALAN R. DAHL, Senior Inhalation Toxicologist, Lovelace Inhalation Toxicology Research Institute, Albuquerque, New Mexico
WILLIAM EICHER, Major General, U.S. Army (Retired), Laurel, Maryland
CHESTER GRELECKI, President and Chief Scientist, Hazards Research Corporation, Rockaway, New Jersey
ERSKINE E. HARTON, JR., Consultant, Falls Church, Virginia
PHILIP E. HICKS, President, Hicks and Associates, Orlando, Florida
WALTER B. LABERGE, Vice President, Planning and Technology, Lockheed Missiles and Space, Sunnyvale, California
RONALD M. LATANISION, Shell Distinguished Professor of Materials Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
RICHARD A. MATULA, Dean, College of Engineering, Louisiana State University, Baton Rouge, Louisiana
WILLIAM G. MCMILLAN, McMillan Science Associates, Los Angeles, California
AARON NOVICK, Professor, Institute of Molecular Biology, University of Oregon, Eugene, Oregon
CARL R. PETERSON, Associate Professor, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts
DENNIS L. PRICE, Professor, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute, Blacksburg, Virginia
HAROLD E. PRICE, Vice President, Essex Corporation, Alexandria, Virginia

ARNOLD W. REITZE, JR., Professor of Law, National Law Center, The George Washington University, Washington, D.C.

CEDOMIR M. SLIEPCEVICH, Department of Chemical Engineering, Flame Dynamics Laboratory, University of Oklahoma, Norman, Oklahoma

ROBERT C. SPEAR, Professor of Environmental Health Sciences, School of Public Health, University of California, Berkeley, California

TELFORD WORK, Professor of Infectious Diseases, School of Public Health, University of California, Los Angeles, California

ZIVIA S. WURTELE, R&D Associates, Marina del Rey, California

Staff

DENNIS F. MILLER, *Study Director*
HOWARD E. CLARK, *Staff Officer, Technology Assessment Panel*
MICHAEL GAFFEN, *Staff Officer, Stockpile Assessment Panel*
HELEN D. JOHNSON, *Administrative Associate*
LEE CARLSON, *Administrative Secretary*
DONNA BROACH, *Administrative Secretary*
JUNE RICHARDSON, *Administrative Secretary*

Stockpile Assessment Panel

HARRISON SHULL *(Chairman)*, Chancellor, University of Colorado, Boulder, Colorado
LEO G. ABOOD, Professor, University of Rochester Medical Center, Rochester, New York
ALAN R. DAHL, Senior Inhalation Toxicologist, Lovelace Inhalation Toxicology Research Institute, Albuquerque, New Mexico
WILLIAM EICHER, Major General, U.S. Army (Retired), Laurel, Maryland
RONALD M. LATANISION, Shell Distinguished Professor of Materials Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
D. WARNER NORTH, President, Decision Focus, Inc., Los Altos, California
AARON NOVICK, Professor, Institute of Molecular Biology, University of Oregon, Eugene, Oregon
ARNOLD W. REITZE, JR., Professor of Law, National Law Center, The George Washington University, Washington, D.C.
CEDOMIR M. SLIEPCEVICH, Department of Chemical Engineering, Flame Dynamics Laboratory, University of Oklahoma, Norman, Oklahoma
ROBERT C. SPEAR, Professor of Environmental Health Sciences, School of Public Health, University of California, Berkeley, California
TELFORD WORK, Professor of Infectious Diseases, School of Public Health, University of California, Los Angeles, California

Staff

MICHAEL GAFFEN, *Staff Officer*
DONNA BROACH, *Administrative Secretary*

Technology Assessment Panel

ROBERT W. BUCHHEIM *(Chairman)*, formerly Deputy Assistant Director, U.S. Arms Control and Disarmament Agency, Phoenix, Arizona
CHARLES H. BEDINGFIELD, Principal Consultant, E. I. duPont de Nemours & Company (Retired), Newark, Delaware
AUSTIN W. BETTS, Consultant to the President, Southwest Research Institute, San Antonio, Texas
CHESTER GRELECKI, President and Chief Scientist, Hazards Research Corporation, Rockaway, New Jersey
ERSKINE E. HARTON, JR., Consultant, Falls Church, Virginia
PHILIP E. HICKS, President, Hicks and Associates, Orlando, Florida
RICHARD A. MATULA, Dean, College of Engineering, Louisiana State University, Baton Rouge, Louisiana
CARL R. PETERSON, Associate Professor, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts
DENNIS L. PRICE, Professor, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute, Blacksburg, Virginia
HAROLD E. PRICE, Vice President, Essex Corporation, Alexandria, Virginia

Staff

HOWARD E. CLARK, *Staff Officer*
JUNE RICHARDSON, *Administrative Secretary*

Board on Army Science and Technology

Preface

This report responds to a request from the Department of the Army to the National Research Council (NRC) for a study to recommend the most effective, economical, and safest means for disposing of the Army's aging and obsolete stockpile of chemical agents and munitions.

In a November 3, 1982, letter to Martin Goland, chairman of the NRC's Board on Army Science and Technology, James R. Ambrose, Undersecretary of the Army, stated: "The United States faces a formidable problem in disposing of its current obsolete chemical munitions and agent stockpile. About 90 percent of the inventory of chemical agent and nearly as much of the munitions inventory has little or no military value and will require disposal regardless of future decisions regarding the binary weapons program. The cost of disposal will be significant. Estimates range as high as $4 billion. R&D efforts are underway to seek less expensive ways of safe disposal. In the meantime, the current stockpile — some in a state of physical deterioration — must be kept safe and secure."

In response to the Army's request, the NRC's Commission on Engineering and Technical Systems established a Committee on Demilitarizing Chemical Munitions and Agents under the Board on Army Science and Technology in August 1983.

The committee, the first nongovernment group to study the whole range of U.S. chemical weapons since a previous National Academy of Sciences report issued in 1969, consisted of 25 members. In addition to members with expertise in such scientific and technological areas as chemistry, environmental sciences, toxicology, and industrial, mechanical, chemical, and human factors engineering, members were also selected who had knowledge of law, public health, systems safety, industrial safety, and the storage and handling of explosives.

Before proceeding with its task, the committee found that information was needed on the current stockpile. Its status would largely determine what technology would be recommended for disposal of chemical agents and munitions. Because of the one-time nature of disposal, once a technology is put in place, it would be very costly to modify or replace it.

If the chemical weapons were found to be deteriorating rapidly, then current technology would, of necessity, be recommended. However, if the stockpile were found to be relatively stable, then the current technology, which dates to the 1960s, could be replaced by safer technologies, which will become available later in the 1980s or the 1990s.

Thus, the Army specifically asked the committee to:

- Evaluate the stockpile's current status for each type of chemical munition and for each location.
- Assess the potential for and possible consequences to public health of an accident or incident involving the release of chemical agents into the atmosphere in terms of high, medium, and low probability.
- Determine the urgency of disposing of each type of chemical agent and munition.
- Assess the Army's current and planned disposal programs and the technology now available for carrying them out.
- Suggest alternative technologies or new approaches that should be considered prior to any decision on how to dispose of the U.S. stockpile of chemical agents and munitions.

To conduct its study, the committee created two panels out of its membership. The first addressed the issue of the current stockpile of chemical munitions and its safety. The Stockpile Assessment Panel sent questionnaires to and visited all eight sites in the continental United States where the Army stores chemical munitions. The panel also heard Army briefings at each site on the status of stored chemical agents and their potential hazard should any be accidentally released, and it heard from private industry representatives.

The full committee met on October 18-19, 1983, at Aberdeen, Maryland; on December 6-7, 1983, in Salt Lake City, Utah; and again on April 4-6, 1984, in Washington, D.C. Members of the Stockpile Assessment Panel visited the Lexington-Blue Grass depot on November 29, and the Newport, Indiana, depot on November 30, 1983. The entire committee met and visited the Tooele, Utah, depot on December 7-8, 1983. Additional site visits by panel members were made to Umatilla, Oregon, on January 11-12; Anniston, Alabama, on January 24; Pine Bluff, Arkansas, on January 25; and Aberdeen, Maryland, on March 8, 1984. The full panel met and visited the Pueblo, Colorado, depot on February 15-16, 1984.

The second panel—the Technology Assessment Panel—reviewed the technologies now available for disposing of chemical weapons and assessed alternative technologies and new approaches that might be used in the future. This panel also reviewed current and planned Army disposal programs. It, too, received briefings from Army and private industry experts in addition to its visits to three of the Army storage facilities. The panel met in San Diego, California, on January 10-12, 1984, and in Washington, D.C., on February 8-9 and on February 29-March 2, 1984.

The Technology Assessment Panel developed a file of resource documents with the assistance of the Army and various other contributors. This file contains about 150 documents covering a great variety of subjects and technical data on topics such as chemical munitions, transporting hazardous materials, processes for destroying chemical weapons, system safety, human factors, and legislation and regulations relative to chemical weapons. In addition, the general literature within the disciplines of panel members was consulted. Such sources are referenced throughout this document.

In the original design of this study, a third panel of experts was to consider issues raised by the potential need to transport chemical munitions from one depot to another. Such movement might be necessary for storage, safety, or disposal reasons. Unfortunately, because of the lack of Army funds and for other reasons, the third panel could not be established.

Instead, both the stockpile and technology panels addressed aspects of the transportation problem. But both lacked sufficient expertise and information to analyze in detail the safety, costs, legality, and politics of transporting chemical munitions.

The committee and its two panels recommend that the Army initiate a technical study of transporting chemical munitions. Such a study should in no way interfere with current or planned programs to dispose of chemical weapons. Without such a study, however, the efforts of this committee will be incomplete.

There were several issues that the committee did not address. For one, the committee did not study the question of U.S. chemical weapons stored in other countries. The committee considered neither the likelihood of chemical weapons being used in wartime nor international negotiations that might lead to a treaty for their disposal. Also, the committee did not deal with the binary munitions issue. These issues were outside the committee's charge.

On the other hand, in case international negotiations lead to a treaty for the disposal of chemical weapons, the committee did consider the need to verify that chemical agents and munitions are in fact disposed of.

The committee's report is divided into four parts. The first represents the joint report of the committee's two panels. It includes the executive summary and the introduction. The second and third parts consist of the reports of the stockpile and technology assessment panels, respectively. The fourth part contains the appendices and includes a glossary of acronyms and terms.

This report is based on a study carried out between October 1983 and May 1984. The report contains many suggestions for program direction and improved procedures. Some of these may have been put in place in the interim and the committee regrets not crediting the Army or its appropriate agencies for so doing. The committee also notes that the existence of such a wide ranging study as this one often has in itself a saluatary effect on the institutions or organizations being reviewed.

In conducting its study, the committee received advice and assistance from a great number of individuals representing various Army units, government agencies, and private organizations. We thank them all.

The committee also wishes to thank Dennis F. Miller, executive director of the Board on Army Science and Technology, for his guidance in organizing and coordinating the study, and for his perspective in preparing this report. Thanks also go to Michael

Gaffen and Howard E. Clark, staff officers for the stockpile and technology assessment panels, respectively, for their efforts on the committee's behalf.

Similarly, thanks are due to John E. Wagner, who joined the study in its later phases and helped to coordinate the preparation of the final joint report, and to Jeffrey Cohn, who applied his editorial craft with skill. Finally, we want to thank Helen Johnson, Donna Broach, Lee Carlson, June Richardson, and Cheryl Woodward for their support throughout the study. Without their efforts and long hours, this report could not have been completed.

Contents

Tables

Figures

1

Executive Summary

For more than half a century, the United States has maintained a stockpile of highly toxic chemical agents and munitions for possible use in a wartime situation. The United States maintains its stockpile principally to deter other countries from using such munitions against U.S. forces. Four basic chemicals are kept. These are the nerve agents VX, which is persistent in its effects, and sarin (GB),* which is nonpersistent; the mustard agents H, HD, and HT, which are usually referred to simply as H; and the hallucinogenic agent BZ.

These chemical agents are stored at eight U.S. Army depots in the Continental United States as well as on Johnston Atoll in the Pacific Ocean. The latter depot was not a part of this study. Each depot varies in size, in the type and number of agents and munitions in storage, and in its proximity to off-site civilian populations. Moreover, the agents are kept in a variety of containers and munitions--rockets, land mines, artillery and mortar shells, bombs and spray tanks, and bulk containers.

MANAGING THE STOCKPILE

The Army has a very good record of safely managing its stockpile of toxic chemical agents and munitions. All storage depots seem to be conforming with relevant Army regulations and procedures designed to ensure the safety and security of the stockpile. Further, the stockpile has remained relatively static; e.g., most movements of munitions and containers take place within each storage depot and are done for surveillance, maintenance, and management purposes. Only occasionally are very small laboratory samples sent from one depot to another for testing.

Most important, there have been no accidents and only three minor incidents in the last two years related to handling chemical agents and munitions.** In none of those cases was any toxic agent released

*See Glossary of Acronyms.
**The period covered by the site visit questionnaire (Appendix B).

to the outside atmosphere. Workers suffered only minor injuries; nearby residents were not injured at all.

Thus, the committee concludes that:

- o The Army is competently managing the task of preserving the stockpile of toxic chemical agents and munitions.

Maximum Credible Event

Each depot prepares for possible accidents or incidents by planning for a "maximum credible event." The maximum credible event indicates the toxicological effects of a release for each type of available toxic chemical under different meteorological and atmospheric conditions based upon Army diffusion modeling. The Army has a set of standard procedures for computing the area in which adverse health effects are likely to occur should toxic chemicals accidentally be released. The main calculation is the distance downwind at which a 1-percent lethality will occur in an unprotected population.

In some cases, however, realistic scenarios could be designed to simulate events that, if they occurred, would have more severe consequences than the depot's official maximum credible event.

- o The maximum credible event at each site should be reviewed critically for completeness and accuracy, especially in light of potential terrorist threats and natural disasters. The possible impacts of each maximum credible event should be evaluated as soon as possible.

Sensors

While generally quite good, two other areas of the Army's management of its chemical weapons stockpile require improvement. First, the Army uses perimeter detectors periodically to monitor storage igloos for leaking munitions and containers. Direct monitoring is done only when the igloos have to be entered for inventory or other routine inspection. Instead,

- o Continuous monitoring of exhaust vents would provide better early detection of leakers and increase the safety of those who must enter the igloos.

Medical

Second, each depot has a medical unit that is responsible, among its other duties, for treating injuries resulting from toxic chemicals.

However, this responsibility seems to be regarded as a secondary one. Most medical officers lack specific training in treating injuries from chemical agents. In addition, these officers are rotated in such a way that incoming physicians, nurses, and other health professionals do not have an opportunity to learn from those whom they are replacing.

The committee concluded that:

- Most of the problems with medical personnel are amenable to straightforward solution.
- Priority should be given to the selection of properly qualified personnel who are then trained in dealing with the medical consequences of working with toxic chemicals prior to their assignment to the depots.
- Each medical contingent should have adequate reference material to treat chemical injuries.

Condition of the Stockpile

Regarding the stockpile itself, all chemical agents maintained by the Army are at least 16 years old and some are more than 40 years old. None has been manufactured since 1968. Some munitions have begun to leak. Many munitions have become obsolete or unserviceable. Many months would be required before significant additional quantities could be made ready for military use. This equals or exceeds the time required to manufacture new chemical agents and munitions.

While there is no evidence that any chemical agents, munitions, or their containers are deteriorating at an accelerating rate, parts of the stockpile are deteriorating. This poses some finite risk both to off-site civilian populations and to those who must work at the depot. It is also expensive to safeguard and maintain.

- The stockpiles of obsolete or unserviceable toxic chemical agents and munitions, including bulk stocks, should be destroyed as soon as possible. For the present time, however, storage is the only option.

The Army is currently loading burster charges into munitions already containing chemical agents. This makes them more useable as a military munition, but also makes them more difficult to dispose of safely.

- Given the age of most of its stock and the condition of its weapons, the Army should discontinue uploading burster charges into chemical munitions.

In addition, the condition of the munitions is uncertain from an ordnance standpoint. No test firings have been conducted since 1969.

To renew such tests, which were banned by law in 1969, the President and Secretaries of Defense and of Health and Human Services would have to concur and report to Congress--a complex and lengthy process.

Finally, international negotiations might lead to a treaty requiring the destruction of all chemical agents and munitions. Such disposal would, no doubt, require verification. At the same time, production of new, safer, binary compounds for use as chemical weapons may be linked, by law, to destruction of current stocks.

Thus, it seems appropriate (1) to destroy as soon as possible those obsolete and unserviceable munitions that pose the greatest risk to workers and nearby residents, and (2) to develop new technology that would enable the safe disposal of remaining stocks at the lowest feasible cost. This will require the construction of new disposal facilities or the possible transportation of chemical munitions from their current storage depots to places where disposal facilities are now or soon will be available.

M55 Rockets

Among the chemical munitions, the M55 rockets are the most dangerous items in the current stockpile. They are loaded with either agent VX or GB and have fuzes, burster charges, and propellants in place. M55 rockets are the source of the greatest number of leaking munitions and are the leading concern in each depot's maximum credible event because of the possible harm they can inflict on workers and civilian populations.

- The Army should give top priority to disposal of the M55 rockets as soon as possible.

There is no evidence that waiting for the development of more advanced technology for disposing of M55 rockets will reduce either costs or risks.

- Facilities to dispose of M55 rockets should be designed to be capable of being modified later to dispose of other chemical agents and munitions. Apparently the Johnston Atoll Chemical Agent Disposal Systems (JACADS) facility will be designed to provide such a capability and the M55 plants are being so designed. Due consideration should also be given to such design improvements as simplified shearing devices and decontamination furnaces that avoid rotary seals, which may be subject to leakage.
- Moreover, the committee believes that safety must be the primary consideration for the disposal of all chemical munitions. Safety must come first.

According to some early estimates, disposing of the entire stockpile could cost as much as $4 billion and take up to 20 years to complete, using current technology. More recent estimates place the cost and duration at less than half those amounts. In any case, the task will be difficult and costly, and R&D efforts are under way to find less expensive technological approaches for both safe and effective disposal.

POSSIBLE USE OF FACILITIES AFTER AGENT DISPOSAL

The Department of Defense (DOD) generates a substantial quantity of industrial and hazardous waste that needs to be disposed of in an environmentally acceptable manner. It may be possible to reduce substantially the life-cycle costs of the chemical agent disposal system if all the incinerators could be subsequently used by federal, state, and local governments and private industry to dispose of hazardous wastes. The life-cycle costs could similarly be reduced if the plants were also designed to produce steam and/or electricity, which could be used by DOD.

- The Army should explore the potential for use of chemical agent disposal facilities for disposal of DOD wastes, and perhaps for wastes and hazardous materials from other sources. This exploration should precede final facility design in order to accommodate design features that might economically and safely facilitate such future use.

TECHNICAL OPTIONS

Prior to 1972, most obsolete chemical agents and munitions were disposed of by dumping them in the deep ocean. In 1969, however, a National Academy of Sciences report recommended that ocean disposal be avoided and that new, safe, and environmentally acceptable methods be sought. In 1972, Congress prohibited ocean disposal.

One alternative is to use chemical processes such as hydrolysis, caustic neutralization, anhydrous chlorinolysis, and aqueous chlorinolysis. Such methods, however, are difficult and slow for the agents and munitions in the current stockpile, although they could be used to decontaminate the disposal plant and equipment. Chemical methods also produce large quantities of hazardous waste materials that must be stored until acceptable disposal methods are found.

Another suggested alternative is to place the chemical agents and munitions in underground cavities and destroy them in a nuclear explosion. The agents and munitions would not require unpacking and would be completely destroyed. However, the method faces great geological and political hurdles, especially in finding acceptable sites, in creating the cavities, and in transporting the chemical munitions from their existing storage depots.

More conventional thermal processes destroy chemical agents either by incineration or by pyrolysis, in which the agents are heated in the absence of oxygen. The Army has demonstrated that all four agents can be destroyed effectively by incineration. A facility at Rocky Mountain Arsenal near Denver, Colorado, was used in the 1970s to burn more than 3,000 tons of mustard. Additionally, an experimental pilot plant at Tooele, Utah, has been used to incinerate more than 14 tons of GB and three tons of VX. Most importantly, these operations have been conducted with no chemical-related injuries or environmental releases.

The Army has also studied various novel technologies that might be used in disposal processes. Of the dozens examined, only one is advanced enough to be potentially useful. Called "in-shell combustion," it involves incinerating the agent within its munitions case. The concept might be valuable when used with other thermal processes or in a mobile disposal system.

- Considering the above advantages and disadvantages of each disposal method, thermal destruction is the preferred means for disposing of the current stockpile of chemical agents and munitions. The Army has already selected thermal destruction as the most appropriate method. The committee supports this decision.

Thermal disposal requires destruction of the chemical agent, deactivation of associated explosives and propellants, decontamination of metal parts, and disposal of packing material or containers. The process typically involves moving the chemical agents and munitions from their storage site to the disposal facility, unpacking the containers, and gaining access to the agent and explosives.

There are several design constraints in developing thermal disposal facilities. First, disposal must be conducted in a way that ensures the safety of all personnel and nearby residents, and also protects the environment. Second, the project aims to destroy, not create, agents; therefore, it has a terminal nature.

Current Disposal Technologies

Two programs are already in operation to dispose of obsolete or unserviceable chemical agents and munitions. One is the Drill and Transfer System (DATS), which is based at the Army depot in Pine Bluff, Arkansas. DATS consists of a small, trailer-mounted system that travels from depot to depot to remove and store toxic chemical agents from leaking munitions.

The second program is the Chemical Agent Munitions Disposal System (CAMDS), a prototype research facility at the Army depot in Tooele, Utah. It tests various chemical and thermal processes for disposing of all agents and munitions. The high initial estimates for the cost and duration of a disposal program reflect, in part, the experience with such an experimental facility.

A third disposal facility is scheduled to be built on Johnston Atoll to destroy the chemical agents and munitions stockpiled there.

The facility, known as Johnston Atoll Chemical Agent Disposal System (JACADS), will be based on the equipment and processes used at CAMDS. Yet another facility is planned for the Pine Bluff depot to dispose of the BZ stored there.

The "baseline technology" developed at CAMDS can serve as a reference point against which new or improved equipment and processes can be judged. The technology at CAMDS includes a straightforward punch and shear to gain access to the agent in bulk containers, rockets, and land mines, and to disassemble artillery and mortar shells. A rotary kiln is used to deactivate explosives and an electrically heated discharge conveyor is used to decontaminate metal fragments. A large three-chamber furnace is used to volatize the chemical agent and decontaminate metal parts.

Other key equipment at CAMDS includes a liquid incinerator for agents drained from munitions and a separate incinerator for dunnage, an explosive containment chamber, dryers to extract salts (which must be stored) from scrubber liquids, and pollution control systems, which will ensure that toxic vapors or other industrial pollutants are not emitted into the air.

Although based on CAMDS, the JACADS and M55 disposal programs are markedly improved and simplified. For example, a rocket shear (currently being tested at CAMDS) will replace the original saw. Multielement linear conveyors between operation stations are to be replaced by "carousel" production machines. Also, a more accessible layout is being designed.

While the JACADS design is much improved over CAMDS, numerous opportunities still exist to further simplify the thermal disposal process. Agents in bulk containers can be destroyed with equipment that is simpler and less costly to operate than the large, three-chambered furnaces at CAMDS. Volatizing bulk agent is not only a slow process, but a difficult one to control. The three-chambered furnace was designed out of concern that mustard and other agents might have solidified or jelled in storage sufficiently to prevent drainage. Recent tests, however, have shown that this may not be the case. More economical drainage processes are under consideration.

Designs that would provide a steadier flow of materials through the disposal system would similarly simplify and speed up the process. One way would be to use vapor pressure instead of a somewhat fragile mechanical device to force the burster well out of artillery shells.

- The Army should explore such alternatives as punching and draining these bulk containers with subsequent combustion of the agent in controlled-feed liquid incinerators (perhaps along with agent drained from munitions). Simpler decontamination procedures should be developed or, alternatively, containers might be chemically decontaminated, crushed to reduce volume, and shipped safely to a central site for final heat treatment or possible ocean disposal.

This report discusses several specific design simplifications for the Army's consideration.

Because of the number and variety of different munitions, some of which have manufacturing defects that are poorly documented, disassembly is an inherently complex operation. Cryofracture has therefore been proposed as a means to simplify the mechanical disassembly of munitions.

Cryofracture uses liquid nitrogen to cool munitions casings to the point where they become brittle and are easily fractured with either a drop hammer or press. The process appears quite promising, having already been successfully demonstrated on some artillery shells, but not yet on fuzed munitions. M55 rockets, however, have aluminum casings that do not become brittle and might even be strengthened at liquid nitrogen temperatures. Cryofracture is not appropriate for them.

The first consideration in any disposal process is safety. It is significant that because of its concern for safety the Army has not had any fatalities or serious injuries resulting from disposal operations. To date the Army has safely and successfully incinerated more than 3,100 tons of mustard and has chemically neutralized more than 4,200 tons of nerve agent. However, an excellent safety record is no guarantee that accidents will not happen in the future. Nor is it a guarantee that CAMDS technology and techniques will be used safely at other depots if the depot personnel are less experienced and not well trained in disposal methods.

INSTRUMENTATION NEEDS

As part of a safety effort, better monitoring equipment is needed. For example, no satisfactory techniques have yet been demonstrated for monitoring, in real time, low-level concentrations of VX in air or stack emissions.

- The Army should undertake an accelerated program to develop instruments that can warn operators of disposal facilities before agent concentrations reach hazardous levels. These might include instruments and auxiliaries whose critical parts operate at temperatures in excess of the boiling point for VX (300°C).

SYSTEM SAFETY

One way to help ensure the safety of future disposal operations is to combine deductive analytical techniques with inductive ones in the design process. The deductive approach assumes an undesirable event and searches for its possible causes. An inductive analysis begins at the level of a component failure and follows that through to resulting undesirable events. Used together, these two approaches allow for cross-checking that enhances the search for all potential hazards in the disposal process.

The safety effort at CAMDS has been limited to what was deemed feasible for a pilot facility. Thus, it is not easy to trace the timeliness and disposition of various safety recommendations. Nor is there any indication of an ongoing effort to include a formal safety analysis in design changes.

The safety program at JACADS is an improvement over that at CAMDS. Nevertheless, some analyses lack appropriate studies of job safety and task assignments. Nor are emergency situations or operator overloads adequately addressed. Analyses performed to date are limited to primary failures and do not consider how interaction among different equipment components might produce multiple failures. The safety analysis at JACADS is continuing; however, it still could include these missing elements.

Some human factors considerations have been included in the CAMDS design and development activities, but they are neither extensive nor well integrated. JACADS planners have developed additional criteria for human-factors engineering, particularly in the area of the human-machine interface. However, there is no task analysis and no specific methodology or criteria for allocation of functions. A more comprehensive and integrated human-factors effort is necessary if personnel errors and performance degradation are to be minimized. More formalized training plans also need to be developed.

- An adequately staffed organization of system-safety engineers, human-factors engineers, and other safety-related specialists should be assembled. They should focus exclusively on the program to dispose of chemical munitions to ensure a continuous, coherent safety program throughout the life of the program. This organization should be responsible for:

  - Immediately installing an information system to track and correct identified hazards.
  - Ensuring that quantitative analytic techniques are used to identify single-, dual-, and multiple-fault paths, where appropriate. Additionally, these techniques should be cross checked--inductive against deductive and vice versa--and be appropriately applied throughout the life cycle of the system.
  - Conducting a timely safety and human-factors review of all engineering and management changes, designs, operations, and procedures.

TRANSPORTATION

Finally, the Army has yet to decide whether to build disposal facilities at all eight depots in the continental United States, to build them at only the five depots where M55 rockets are stored, or to build just a few regional disposal facilities and consolidate the chemical agents and munitions for ultimate disposal at these sites.

What is not well known is whether it would be safer or less costly to dispose of chemical agents and munitions at their current storage site or to transport them to another depot for disposal.

- o The Army should undertake an expedited depot-by-depot assessment of the risks and costs of transporting munitions for disposal at consolidated sites. These results can then be compared with on-depot disposal options. Such a study should examine the potential for carrying stocks from Aberdeen and Umatilla by U.S. Navy vessels to Johnston Atoll for disposal. Transporting stocks from Tooele to Umatilla for subsequent shipment to Johnston Atoll is another option that should be considered.

The Army's transportation considerations are dominated by the very high costs experienced in earlier transport operations. In addition, past contractor studies are contradictory--showing truck transport to be the least costly mode in one study and rail transport in another. Furthermore, hazard and risk analyses have not been done with sufficient rigor either for transport or on-site disposal to permit a meaningful comparison of options.

The Army is considering, but is not now planning, off-depot transportation of these agents. The committee does not recommend such transport. However, since it has not studied the issue in detail, the committee does not have a quantitative basis to dismiss the option since transportation does offer some attractive advantages.

The committee believes that transporting munitions such as M55 rockets to centralized disposal sites would not be safer than on-site disposal. The M55 rockets contain the highest fraction of explosives (and propellant) relative to total weight, and they are fuzed. Additionally, detonations or fires are known to provide enough heat to initiate further detonations. Finally, by design, they can move under their own propulsive power once ignited.

- o Of all chemical munitions, the M55 rocket is the least likely candidate for safe and economical transport. M55 rockets should be destroyed where they are located because they exhibit the highest proportion of leakers and are the weakest agent-containment vessel.

In general, the committee believes that disposal at properly designed and appropriately scaled on-site facilities will cost less than transportation to and disposal at large, central facilities. However, the recommended transportation study should be conducted. The committee is concerned that delay in disposing of the stockpile in the face of opposing public pressures can only result in penalties in cost and safety.

2

Introduction

For more than half a century, the United States has maintained a stockpile of toxic chemical agents and munitions for possible use in wartime. The United States maintains its stockpile principally to deter other countries from using such weapons against U.S. forces.

The U.S. Army maintains all chemical weapons for the U.S. armed forces. They are stockpiled at eight sites in the continental United States. These are the Edgewood area at Aberdeen, Maryland; the Lexington-Blue Grass Depot in Richmond, Kentucky; and the Army depots in Anniston, Alabama; Pine Bluff, Arkansas; Pueblo, Colorado; Newport, Indiana; Tooele, Utah; and Umatilla, Oregon. In addition, the Army stores chemical munitions on Johnston Atoll in the Pacific Ocean southwest of the Hawaiian Islands. This study was concerned only with the eight sites in the continental United States. The geographic location of all nine sites is shown in Figure 1.

The toxic chemicals stored in the United States comprise four basic types. These are the persistent nerve agent VX and the nonpersistent nerve agent sarin (GB), both of which belong to a family of organophosphate chemicals; the mustard agents H, HD, and HT;* and the hallucinogenic agent BZ, which was developed as an incapacitating agent. These agents are discussed in greater detail later in this chapter and in Appendix A.

Additionally, the Army has small laboratory quantities of the chemical agents lewisite, chlorine, and phosgene. Lewisite is a vesicant that causes skin blistering, while chlorine and phosgene are lung irritants. The Army's stockpile of these agents dates mostly from World War I. Because they are already scheduled for disposal, this report does not address them.

Chemical agents are stored in a variety of containers and munitions--rockets, land mines, artillery and mortar shells, bombs and

*The mustard agents H, HD, and HT all refer to various levels of purity of the same basic chemical compound. In general, this report will ignore the distinction and refer to all mustard agents by the designation H.

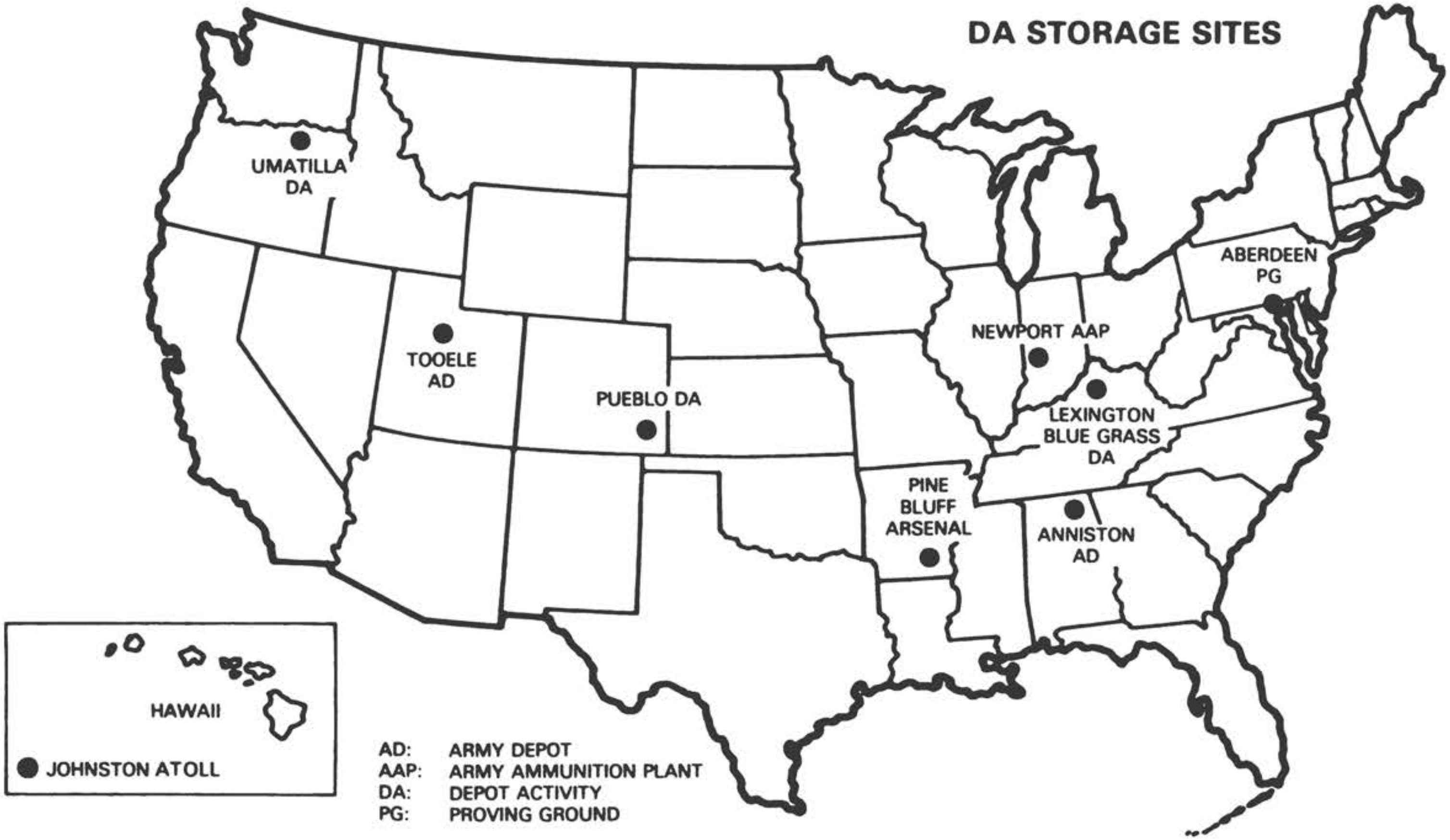

FIGURE 1 Location map of U.S. storage sites.
Source: USATHAMA.

spray tanks, and bulk containers. Some already contain fuzes and burster charges (explosives used to rupture the munitions case and disperse the contained chemical agent), while others do not. Munition characteristics are shown in Table 1.

The M55 rocket is stored as a complete round with shipping and firing tube, rocket motor, rocket-motor igniter, agent-filled warhead, burster charge, and fuze (see Figure 2). The structure consists of a thin-walled aluminum container with a central well that holds the burster charge.

Bulk containers are standard 1-ton tanks in which GB, mustard, or VX are stored. To be used, the chemical agents would have to be removed from the bulk containers and loaded into munitions. In the interest of military readiness, the U.S. Army Materiel Development and Readiness Command (DARCOM) is installing burster charges in chemical munitions that are not classified as obsolete or unserviceable. Spray tanks and MC-1 MK94 bombs, the latter containing GB, are stored without explosives. If required, explosive charges would be added in the field.

In addition to bulk containers, VX is contained in M23 land mines, which are packed three to a shipping package; in M55 rockets, which have fuzes, bursters, and propellants in place; and in artillery shells (8-inch artillery shells). Some M55 rockets also contain GB, as do some artillery and mortar shells. Similarly, mustard is loaded in some artillery and mortar shells as well as in bulk containers. Figures 2, 3, and 4 show the M55 rocket, various bombs and mortar shells, and bulk containers. The relative sizes of these munitions are shown in Figure 5.

The size and contents of the stockpile differ greatly from depot to depot. Since no two sites are exactly alike, there is no "typical" depot. Detailed information on the precise amounts and types of chemical agents and numbers of munitions at each site is classified. Table 2 provides further information on which agents and munitions are stored at five of the eight Army sites in the continental United States for which data are available.

Storage includes both a passive as well as an active maintenance program. Munitions are cleaned, rust is removed, and they are painted. This process is also performed on 1-ton bulk containers. Additionally, the munitions are regularly inspected and inventoried, a process that can require their being handled.

Munitions are subject to more active handling in two cases. In the first, unserviceable munitions are demilitarized under the Army's Drill and Transfer System (DATS). In the second case, lethal agents and munitions are sampled randomly for possible leaks or other defects. The selected munitions are drilled and a sample of the agent is removed for analysis. The munition is then tapped and a plug inserted. It subsequently receives the treatment accorded to "leakers."

TABLE 1 Munitions Characteristics

ITEM	AGENT	FUZES	BURSTERS*
4.2" mortar shells	HD	Yes	Yes
	H	Yes	Yes
	HT	Yes	Yes
105 mm cartridges (i.e. projectiles plus propellant charges)	GB	Yes	Yes
105 mm projectiles	GB	No	No
	HD	No	Yes
	H	No	Yes
	HT	No	Yes
155 mm projectiles	VX	No	Yes
	GB	No	Yes
	HD	No	Yes
8" Projectiles	GB	No	Yes
	VX	No	Yes
Bombs	GB	No	No
Spray tanks	VX	No	Not Applicable
Land mines	VX	Yes	Yes
M55 rockets	VX	Yes	Yes
	GB	Yes	Yes

*The Army is currently in a process to improve readiness by installing burster charges in certain projectiles. Those actions may change some details of this table.

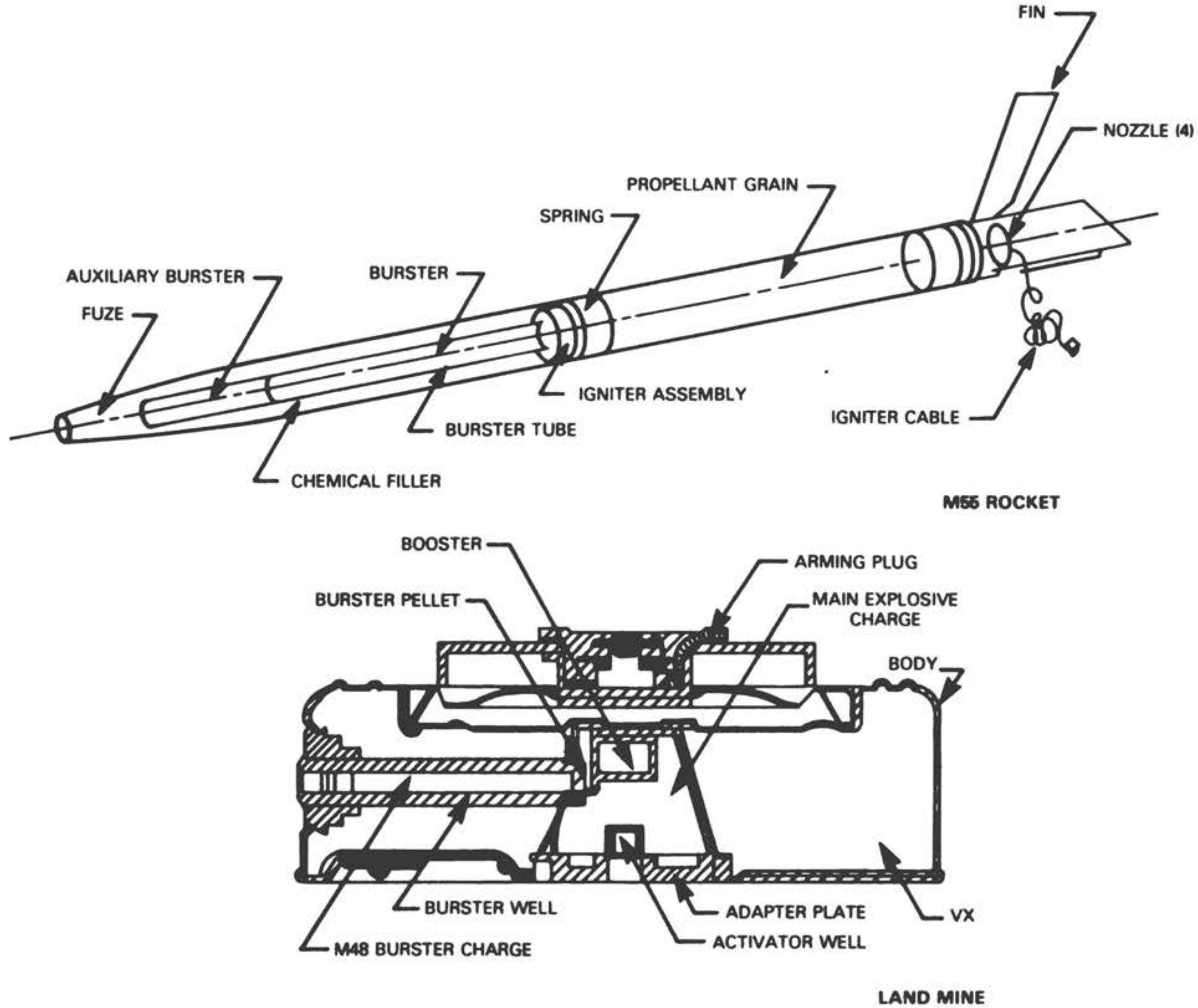

FIGURE 2 M55 rocket and M23 land mine.
Source: USATHAMA.

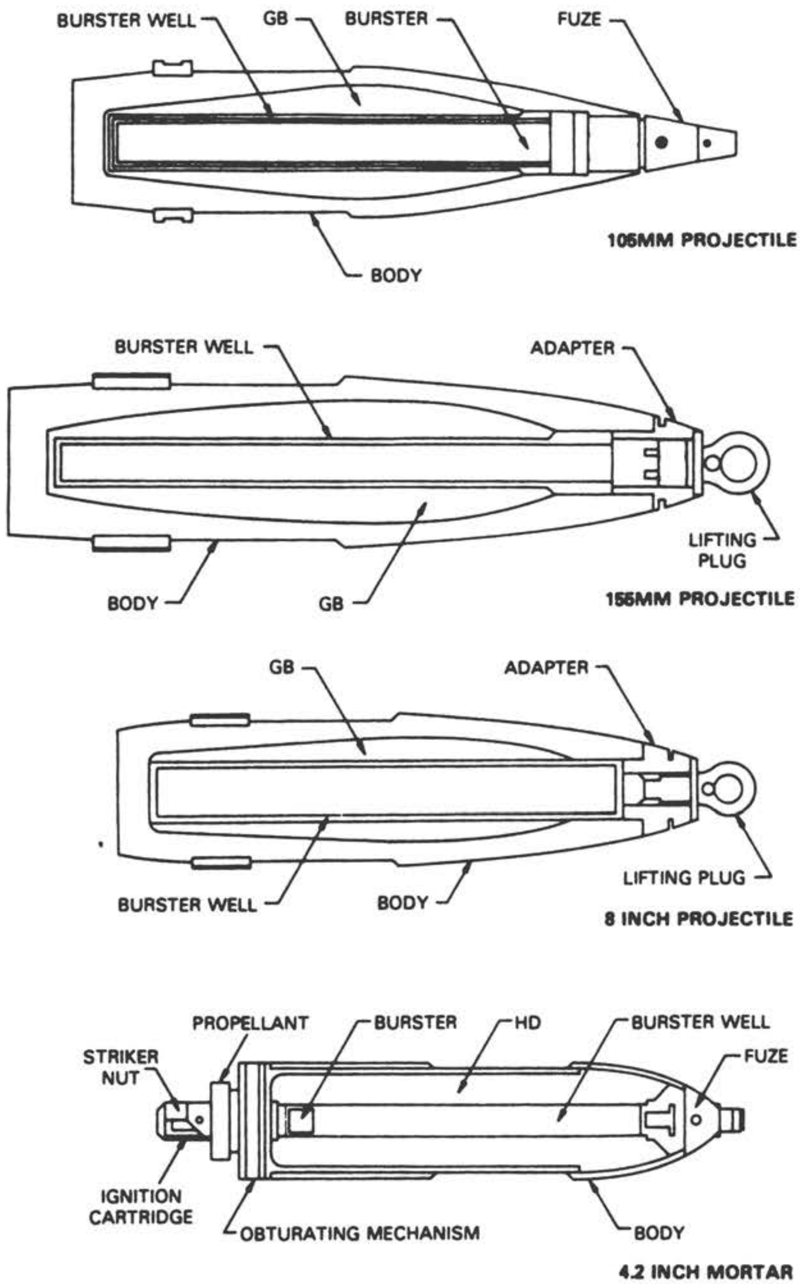

FIGURE 3 105MM, 155MM, 8-inch and 4.2-inch projectiles. Source: USATHAMA.

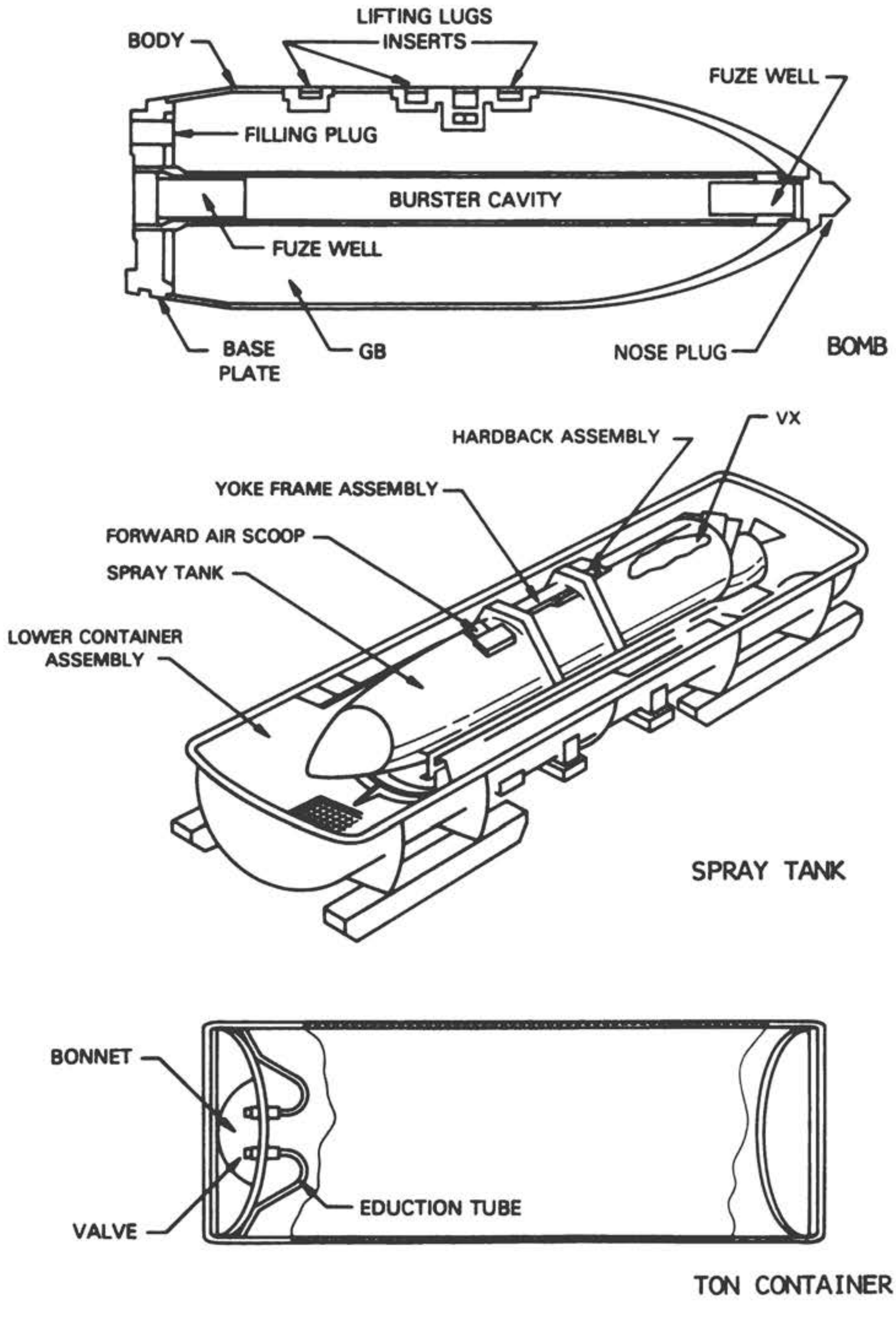

FIGURE 4 Bomb, spray tank, and ton container.
Source: USATHAMA.

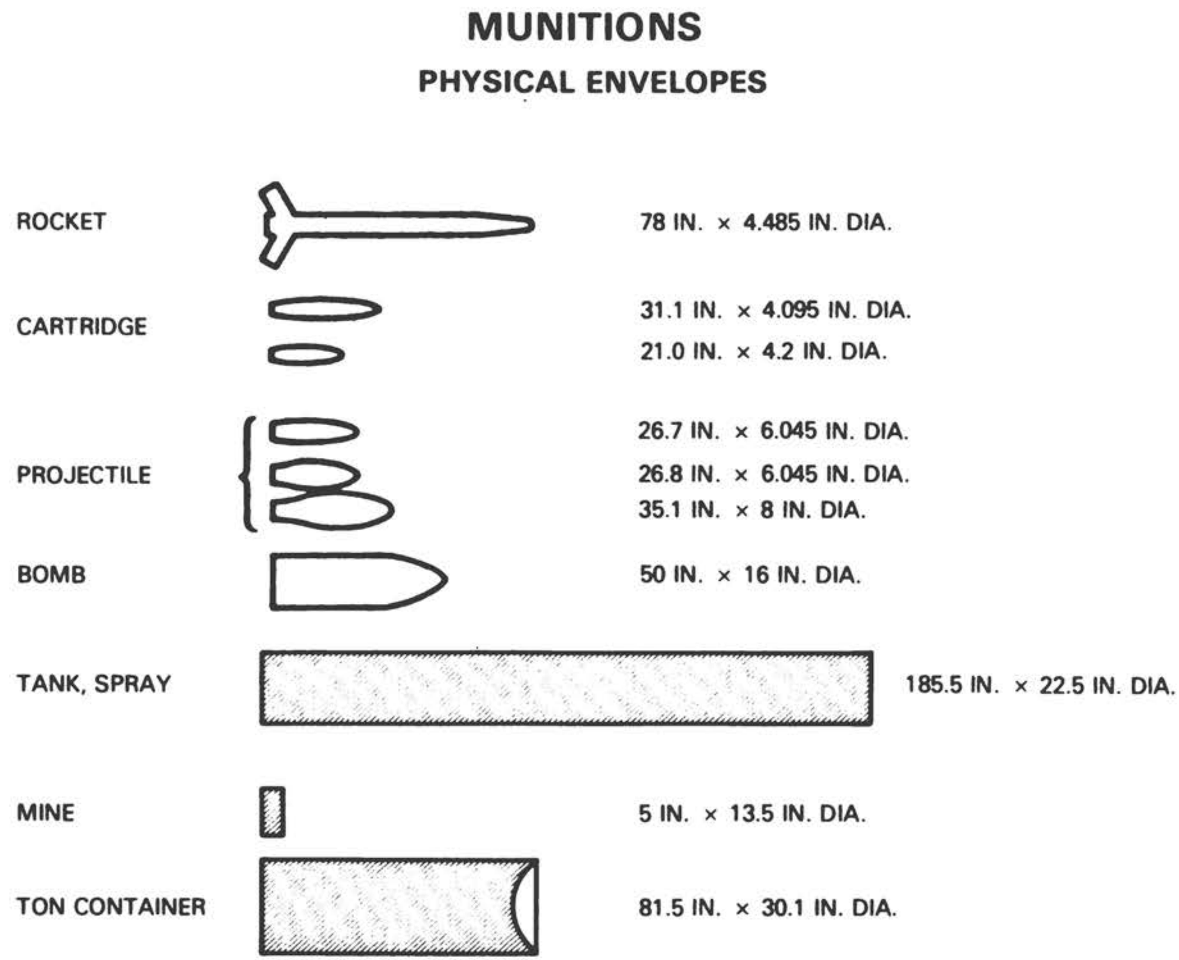

FIGURE 5 Physical envelopes of munitions.
Source: GA Technologies.

TABLE 2 Relative Magnitude of the Stockpile at Selected Army Depots

DEPOT	TYPES OF FILLER	TYPES OF MUNITIONS	TONS OF MUNITIONS
Anniston	GB, VX, HD, H, HT	Artillery, Rockets, Mines, Bulk	22,500
Lexington-Blue Grass	GB, VX, HD, H, HT	Artillery, Rockets	4,000
Tooele	GB, VX, HD, H, HT	Artillery, Bombs, Rockets, Mines, USAF Spray Tanks, Bulk	52,000
Umatilla	GB, VX, HD, H, HT	Artillery, Bombs, Mines, Rockets, USAF Spray Tanks, Bulk	17,000

Passive storage regulations require that all toxic chemical munitions be placed in a special restricted area. All individuals who work with these munitions must have clearance to even approach this high-security exclusion area. The exclusion area is surrounded by a double perimeter fence that is lighted at night. Access to the area is governed by the extensive security requirements outlined in Army documents AR 50-6 and AR 50-6-1. A well-armed guard force is always on duty.

With one exception, all munitions are stored in covered igloos. The exception is bulk mustard, which is stored in igloos, covered warehouses, and in the open with antiaerial devices (to prevent removal by helicopters, for example) in place. The igloos also have individual security systems.

The munitions and bulk agents are inspected and monitored at regular intervals. Army document SB 742-1 governs the schedule and requirements for inspections. Monitoring is controlled by DARCOM-R 385-11, 385-102, and SB 742-1.

Leaking ammunition is overpacked and segregated from other munitions. Leaking bulk containers are either repaired or the agent is transferred to a serviceable container. Leakers are reported to higher authorities.

HISTORY OF DISPOSAL OPERATIONS

No chemical agents or munitions have been manufactured in the United States since 1968. Thus, all those in the U.S. arsenal are at least 16 years old and many are 40 years old or older. Further, except for maintenance, laboratory, and safety purposes, they have rarely been moved. Some leaking munitions have been discovered and sealed in metal containers (see Chapter 3).

The year 1969 was a pivotal date in the disposal of chemical agents and munitions. Prior to that time, there were three common approaches to disposal: deep ocean dumping, land burial, and open-pit burning. During 1967 and 1968, for example, 1,706 concrete "coffins"--each weighing more than 6 tons and containing 30 M55 rockets filled with GB--were sunk in the Atlantic Ocean east of the Naval Ammunition Depot in Earle, New Jersey, at a depth of 7,200 feet (NAS, 1969).

Anticipating further ocean disposal under Operation CHASE, the Department of Defense's (DOD) director of defense research and engineering requested that the National Academy of Sciences (NAS) assess the hazards of such disposal and alternative plans. The 1969 NAS report assumed that "continuing inaction will not reduce the hazards of eventual disposal of the chemicals and munitions intended for disposal in the 1969 Operation CHASE, and in some instances will increase them."

The report concluded:

> It should be assumed that all agents and munitions will require eventual disposal and that dumping at sea should be avoided.

> Therefore, a systematic study of optimal methods of disposal on appropriate military installations, involving no hazards to the general population and no pollution of the environment, should be undertaken. Appropriately large disposal facilities should be regarded as a required counterpart to existing stocks and planned manufacturing operations. As the first step in this direction, we suggest the construction of facilities for gradual demilitarization and detoxification of the remaining M55 rockets.

Three years later, the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532) prohibited any further ocean disposal of chemical agents. Significant quantities of chemical agents subsequently have been destroyed using other methods (see Table 3). From 1969 until September 1976, more than 3,000 tons of mustard agent were incinerated and 21,000 cluster bombs containing more than 2,000 tons of GB were destroyed at the Rocky Mountain Arsenal in Denver, Colorado (U.S. Army, 1982).

In September 1979, the prototype Chemical Agent Munitions Disposal System (CAMDS) began operation in Tooele, Utah (U.S. Army, 1982). CAMDS was designed to test various chemical and thermal disposal processes. It was not designed for large-scale disposal activities. CAMDS has been used to evaluate technology for caustic neutralization and incineration of GB, VX, and mustard. More than 19,000 projectiles and 14,000 rockets, all containing GB, have been destroyed by CAMDS.

The Army completed a successful pilot test of the Drill and Transfer System (DATS) in February 1980 (U.S. Army, 1982). DATS is a small, trailer-mounted system that is moved from one storage site to another to remove chemical agents from munitions that are leaking, unserviceable, unrepairable, or obsolete. After the agent has been drained for safe storage, the munition casing is chemically decontaminated. The drained agent, scrap metal, and inert munition bodies are stored to await final destruction. Consistent with its test mission, DATS can process only about one item per hour.

PRESENT DIRECTIONS

The U.S. Army's Toxic and Hazardous Materials Agency (USATHAMA) currently has seven distinctly different disposal tasks under way (see Table 4). The project descriptions here are based on publications (U.S. Army, 1982) and oral updates furnished by USATHAMA.

Planned Disposal Programs

The Army already has plans to dispose of some parts of the chemical agent stockpile. One plan aims to dispose of the entire stockpile of the mind-altering drug BZ, which is stored at the Pine Bluff Arsenal. Construction is expected to begin in 1984 on a facility to dispose of BZ (see Chapter 13).

TABLE 3 Completed Disposal Projects (As of June 1983)

TASK	LOCATION	COMPLETED	AGENT (thousands of pounds)
Leaking M55 Rockets	Johnston Atoll	Nov 73	.2
Bulk Mustard	Rocky Mountain Arsenal	Mar 74	6,190.2
GB in Underground Tanks	Rocky Mountain Arsenal	Nov 74	382.7
Agent in Concrete Drums (Phase I)	Edgewood Arsenal	Aug 75	32.4
GB in Ton Containers	Rocky Mountain Arsenal	Nov 75	3,605.2
Honest John GB Warheads M139 Bomblets	Rocky Mountain Arsenal	Aug 76	76.5
M34 GB Cluster Bombs	Rocky Mountain Arsenal	Sep 76	4,129.6
M55 Rocket Residues	Dugway Proving Ground	Sep 76	53.2
Chemical Bomblets	Dugway Proving Ground	Sep 77	17.4
Hydrogen Cyanide Bombs	Tooele Army Depot	Nov 78	.3
DATS - Pilot Test	Dugway Proving Ground	Feb 80	.3*
- Operations	Pine Bluff Arsenal	May 81	.3*
	Anniston Army Depot	Jul 82	.3*
	Lexington-Blue Grass AD	Jul 83	1.1
CAMDS - M55 GB Rocket	Tooele Army Depot	Jun 81	128.0
105mm & 155mm GB			98.0
ID Sets - (Multiple Agents)	Rocky Mountain Arsenal	Jan 83	36.7
Phosgene (Carbonyl Chloride)	Rocky Mountain Arsenal	Sep 82	618.4

*Transferred to shipping containers

TABLE 4 Lethal Chemical Demilitarization Program--Major Tasks

PROJECT	LOCATION	COMPLETION	STATUS
Operational Projects			
- DATS			
Leaking and recovered chemical munitions	Multiple	FY84	Operations
- CAMDS	TEAD	FY88	Process Evaluations
Development Project			
- BZ agent/munitions	PBA	FY88	Process Development FY84 MCA
- JACADS	Johnston Atoll	FY92	Process Development FY85 MCA
- M55 rocket	Multiple	FY92	Process Development FY86 MCA
Long-Range Projects			
- RDT&E program	NA	FY89	Laboratory/Bench Testing
- Stockpile	Multiple	FY2001	Planning/Studies

More important are the Army's plans to dispose of chemical agents and munitions shipped from Okinawa to Johnston Atoll in 1971. They were to have been stored in the United States, but Congress amended the Foreign Military Sales Act (PL 91-672) to prevent their entry into this country.

Because Johnston Atoll lacks sufficient igloo space, some chemical weapons are stored in metal warehouses. A substantial part of the stockpile consists of obsolete, leak-prone M55 rockets. The Army estimates that about 40 percent of the munitions stored on Johnston Atoll are unserviceable (USATHAMA, 1982a).

In March 1981, the Army organized USATHAMA to develop and construct a facility, using technology developed at CAMDS, that would be adequate to dispose of all chemical stocks on Johnston Atoll. Current plans provide for a facility to destroy the entire stockpile, but, initially, process equipment is to be procured only for M55 rockets. A decision concerning further process equipment is to be made in 1984. Construction is to begin in 1985 (see Chapter 13).

By modifying the mechanical, munitions-handling system, the facilities designed to dispose of M55 rockets could also be used to dispose of M23 land mines. The Army has not yet decided whether to procure the additional handling equipment needed to deal with these mines. The expedited M55/M23 program would use technology demonstrated at CAMDS.

If current plans are to be implemented, the Army will need additional military construction funding in 1986 for the Umatilla, Lexington-Blue Grass, and Anniston depots where M55 rockets and M23 land mines are stored. The M55 and M23 stocks at Tooele would be disposed of (using the existing CAMDS facility) in the mid-1980s. Starting in 1988, the BZ facilities currently planned for Pine Bluff would be modified to dispose of M55s and M23s.

Technology Development Program

Even after all weapons containing BZ, all M55 rockets, all M23 land mines, and all stocks on Johnston Atoll have been destroyed, substantial quantities of chemical munitions and agents will still remain in the U.S. stockpile. The Army's Research, Development, Test, and Evaluation (RDT&E) program is aimed at identifying the safest and least expensive way to use the technology and facilities developed in these expedited projects, or any appropriate emerging technologies, for destroying the remaining stocks. USATHAMA, however, has not been directed or authorized to proceed with destruction of that stockpile. This report does not address the question of whether or not USATHAMA should.

The Army's RDT&E program has involved a wide search for existing industrial or experimental technologies that might be used to dispose of remaining stocks. The combined literature reviews conducted by Army contractors examined about 300 documents on chemical techniques, 760 on thermal techniques, and 10 on nuclear-explosive destruction. Nearly 60 additional and unconventional approaches were also explored, including geologic plate subduction, destruction in volcanoes, high velocity impact, and biological destruction. More than 1,000 documents referring to various mechanical processes were considered, although some might have been counted more than once (Shatto, 1983).

By applying such criteria as safety, disposal of process wastes, maintainability, and reliability, the list of possible technical approaches was narrowed. For those ideas that survived preliminary scrutiny, economic analyses were conducted, further narrowing the field.

A full systems analysis (Shatto, 1984b) was, therefore, applied to only two chemical approaches, eight thermal technologies, one nuclear explosion, one "novel" approach, and two mechanical techniques. Each analysis involved evaluation of technological feasibility; an analysis of throughput, reliability, availability, and maintainability; and, finally, a detailed estimate of life-cycle costs. Since no system with a recognized safety problem would have advanced to this stage, relative safety was not considered in these analyses.

Based on these analyses, USATHAMA decided to:

- Continue research on cryofracture (i.e., cooling artillery projectiles to very low temperatures where they become brittle and relatively easy to crack) as a method for gaining access to the chemical agent, combined with the use of a rotary kiln for destroying the agent and decontaminating the shell fragments. (In contrast, bulk containers would be penetrated by heat activated chemicals and multiple electrically heated chambers would be used to volatilize the agent for incineration.)
- Continue an effort to demonstrate the feasibility of incinerating the chemicals within their containers, particularly artillery shells. Systems for such "in-munition" incineration might be transported from depot to depot.
- For clarification, conduct laboratory studies on production of difluoro (methyl phosphonic difluoride--one of two chemical components used in binary weapons) as a by-product of chemically destroying GB.
- Examine other possible ways to reduce costs, such as more carefully matching the size and type of disposal facility to the site-specific quantity of agent and/or munitions to be destroyed.

Stockpile Disposal Program

Current Army policy calls for retaining those chemical weapons that are still usable; i.e., neither obsolete nor unserviceable. But the Army also recognizes that budget and schedule information are necessary for planning for their eventual disposal.

USATHAMA plans, by 1985, to recommend a procedure for disposal of the stockpile. This would incorporate experience derived from the

CAMDS, JACADS, and the expedited M55 rocket/M23 land mine projects as well as the results of the RDT&E program and a number of additional studies (including this one). These studies are to consider the technological and political feasibility of transporting stockpiled munitions to regional facilities and provide cost-benefit analyses of competing alternatives.

Currently, two options developed during the original long-range concept study are of interest to Army planners. Option I calls for consolidation of the stockpile items at the Tooele Army Depot in the West and Anniston Army Depot (ANAD) in the East. Option II involves developing facilities at each existing storage site. Between these extremes, there is a broad range of other alternatives, all involving some amount of transportation.

In summary, the four main components of the Army's current chemical weapons disposal program are:

1. Continue safe storage of munitions and agents;
2. Use DATS to clean and store leakers;
3. Proceed with disposal of BZ, M55 rockets, and unserviceable stocks on Johnston Atoll; and
4. Conduct experiments and analyze alternative methods for disposing of the remaining stocks.

The Army's decisions have been and will continue to be strongly influenced by the requirements and constraints under which it operates. These are discussed in the next chapters.

Part II
Report of the Stockpile Assessment Panel

3

Storage of Toxic Chemical Munitions

The U.S. stockpile of chemical agents and munitions consists of M55 rockets (containing GB or VX), M23 mines (VX), 105-mm, 155-mm, 4.2-inch, and 8-inch projectiles (GB, VX, or HD), MC-1 MK94 bombs (GB), and 1-ton containers (GB, VX, HD).

None of these agents or munitions have been manufactured since 1968. All are at least 16 years old and some are 40 years or older. Mustard was made during World War II and in 1954-1955, while BZ munitions were manufactured at Pine Bluff, Arkansas, in 1963-1964, remaining there in storage. The latter consists of about 5 tons as bulk agent and 40 tons blended with pyrotechnic as cluster bombs, plus another 600 tons of contaminated residue.

The chemical munitions are stored at eight Army depots in the continental United States: Lexington, Kentucky; Newport, Indiana; Tooele, Utah; Aberdeen, Maryland; Umatilla, Oregon; Anniston, Alabama; Pine Bluff, Arkansas; and Pueblo, Colorado. Members of the Stockpile Assessment Panel visited the eight storage sites in the continental United States between October 1983 and March 1984. A report presenting an overview of each site is presented in Appendix B. To assist the panel in discussions at the sites, a questionnaire was developed and sent to each facility for response prior to the visit (Appendix C). A typical site response is included as Appendix D.

These facilities vary considerably in the quantity and type of munitions stored. The chemical weapons constitute a relatively small component of the facility's total activities and budget at most of the depots. The facilities also vary considerably in the surrounding civilian population density, climatic conditions, proximity to large metropolitan areas, and the frequency of surrounding ground and air traffic.

With the exception of Newport, where VX is kept in 1-ton containers in a building, the storage method is similar. The nerve agents, either as munitions or in 1-ton bulk containers, and the mustard munitions are stored in steel-reinforced concrete igloos (Figures 6 and 7),* while the bulk mustard is usually stored in 1-ton containers out in the open.

Within the past two years there have been no accidents and only three minor incidents in handling chemical agents and munitions. Two of these occurred at Lexington-Blue Grass during the Drill and Transfer System (DATS) process. One involved a minor spill during laboratory procedures and the other resulted from a defective glove worn by a DATS operator.

The third incident involved a small mustard burn on the thumb of an operator when a leaking munition at Pueblo was being transferred to a container in 1983. None of these cases involved any release of agent to the outside atmosphere. Further, the fact that no serious incidents or accidents have occurred attests to the adequacy of the storage arrangement.

The stockpile has remained relatively static except for movements within the exclusion area for surveillance, maintenance, and storage purposes. In addition, laboratory samples of 1 liter or less may be sent from one facility (usually from Edgewood Arsenal at Aberdeen) to another for testing purposes.

The Army has a very good record in managing the stockpile of chemical munitions and agents. It has preserved the toxic chemical munitions within the limitations imposed by the location of the stockpiles and the subsequent statutes and Department of Defense (DOD) regulations. Further, the various storage sites seem to conform with relevant Army regulations and procedures.

For the future, however, several reservations can be raised:

- Only a small fraction of the inventory of chemical agent is in munitions that are serviceable and ready for use. At least 18 months will be required before significant additional quantities of agent could be put into useable munitions. Based on information obtained from the Army and other sources, the panel believes that this equals or exceeds the time that would be required to manufacture new chemical agents and munitions.
- Despite plans to develop more data on the long-term stability of chemical agents, it is unlikely that this information will be produced in a timely fashion.
- The condition of the munitions from an ordnance standpoint is uncertain because no test firings have been conducted since 1969. Test firings would provide more useful information on the service condition of the stockpile than all of the other nondestructive, chemical tests combined. Such test firings have been restricted by law since 1969. Test firings will require a complex approval process involving the secretaries of Defense and Health and Human Services, the President, and a special report to Congress.

---

*An igloo is a dirt-covered, reinforced concrete bunker approximately 90' long x 25' wide x 15' high used to store toxic or conventional munitions.

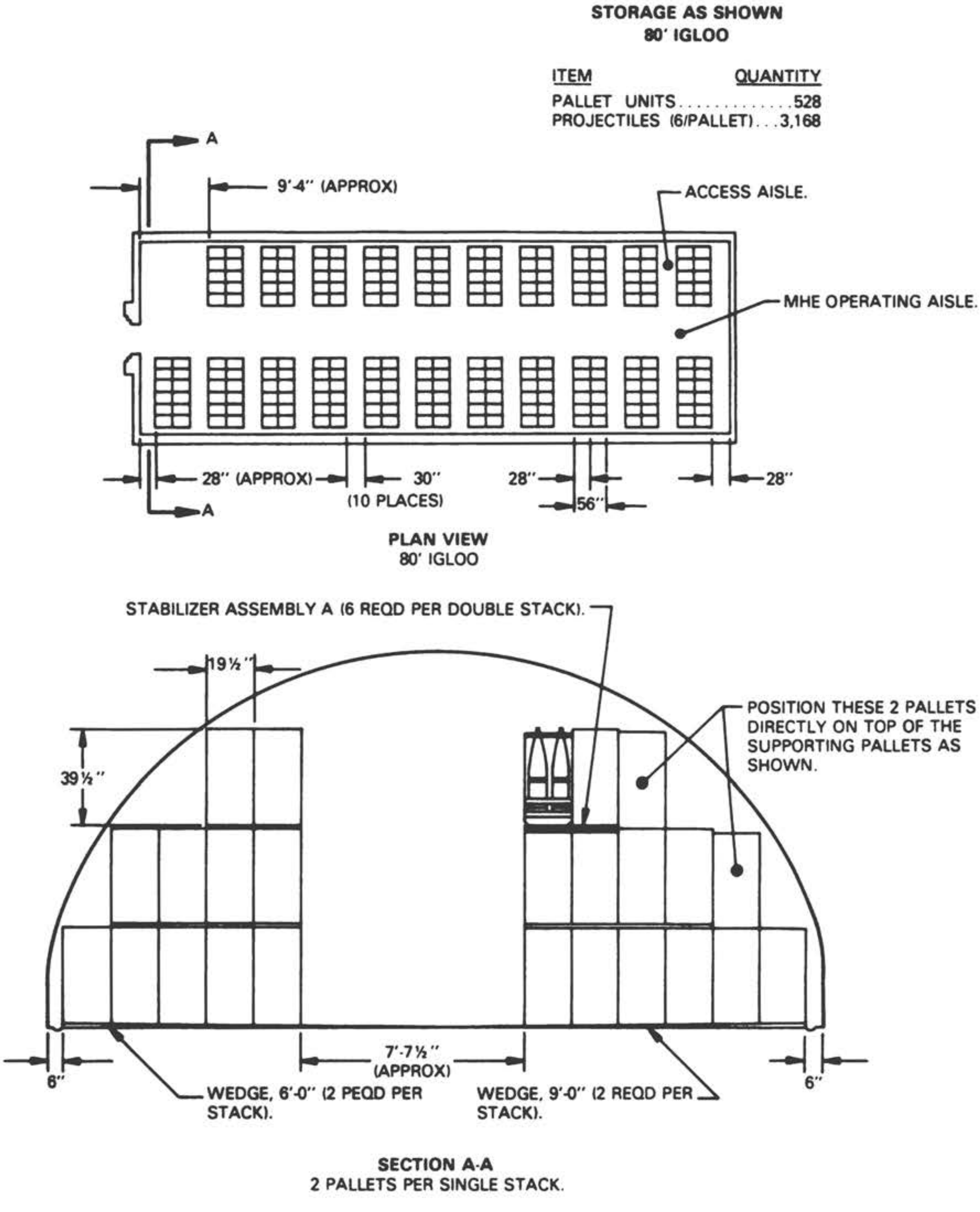

FIGURE 6 Igloo storage plan.
Source: USATHAMA.

FIGURE 7 Storage igloo.
Source: USATHAMA.

MONITORING

The Army has set monitoring requirements for toxic chemical munitions in DARCOM-R 385-31, 385-102, and SB 742-1. Nevertheless, there is considerable diversity in monitoring practices and equipment at the eight depots. Until recently, rabbits were still used instead of instruments at some depots to determine whether igloos had dangerous concentrations of a chemical agent. Bubblers are now used routinely to sample the ambient levels in igloos that are opened, and vents may be tested prior to opening igloos.

Each igloo's exhaust vent should be continuously monitored. Ideally, such monitoring would be connected to the remote electric monitoring already being used for security purposes. However, at the present time, the U.S. Army does not have any sensors capable of providing remote read-outs from point sensors. Microsensors with selective absorbent coatings have the greatest potential for such application, but will not be available for several years (NRC, 1984).

The use of mass spectrometers for identification of chemical agents could be used to determine whether igloos have dangerous concentrations of chemical agent. However, it would be necessary to modify the igloos in order to probe for chemical agent concentrations. In its current state, mass spectrometry would cost about $100,000 to $300,000 per equipment set. A record of emissions from each site should be maintained and be available to the public.

INSPECTION

Monitoring and inspection occur at all storage sites at prescribed intervals in accordance with SB 742-1 (DARCOM, 1977). The method of visual surveillance depends somewhat on the munition. For example, examination of M23 land mines requires removing the munition from its metal container to look for any evidence of leakage, rust, or other signs of deterioration. M55 rockets are examined by drawing a sample of air through openings in the rear and nose cone, and passing it through a detector tube filled with solution. BZ containers are packed in wooden crates, which can be visually examined for leakage and container deterioration. Mustard containers are examined superficially for rust and leakage.

All chemical munitions and agents are inspected on a cyclical basis throughout the year using lot-sampling criteria prescribed by SB 742-1. Each lot is inspected at least once a year; if a leaker is discovered, however, the entire lot is inspected.

In addition to a visual inspection, SB 7421-1 provides for a vapor test and chemical analysis of the agent. However, since these surveillance procedures provide only qualitative information about agent deterioration, the Army initiated the Surveillance Program, Lethal Chemical Agents and Munitons (SUPLECAM).

SUPLECAM uses a mobile chemical laboratory, which is operated by the Pine Bluff Arsenal. The procedure requires that toxic munitions be drilled and the agent be removed and analyzed to determine its characteristics. In addition, the explosive components are tested and the condition of the metal container is assessed. Recently, SUPLECAM II was instituted to provide more data, such as stabilizer percentage, acidity levels, metal content, and purity of the chemical agent, all of which can help predict the useable life of the chemical agent.

Treatment of Leaking Munitions

Over the years, leakers have been overpacked by sealing them in metal containers, which are then stored in specially designated igloos. Starting in 1981, the U.S. Army Toxic and Hazardous Material Agency (USATHAMA) instituted DATS to dispose of all leaking munitions that were designated Code H (unserviceable, unrepairable, or obsolete). This project consists of a transportable chemical laboratory, which is staffed and operated by Pine Bluff Arsenal and which travels to the other depots.

The DATS operation does not destroy the agent or munition; it merely separates the two, which then must be disposed of by other means. A hole is drilled into the munition, and the agent is drained and transferred to a bulk container. The casing is decontaminated and the explosives are destroyed by detonation. The drilling operation is carried out in a glove box. The entire operation appears to have been designed to minimize potential for hazard.

Metallurgical Aspects

With the exception of the M55 rockets, there are few leaks from the bombs, artillery projectiles, spray tanks, mines, and bulk storage tanks in the stockpile. Analysis for metallurgical failure, which has been performed on leakers, has been limited in the past to Navy Wet-Eye Bombs, 105-mm projectiles and, most recently, 155-mm projectiles. The projectile studies have taken place under the auspices of the metallurgical testing program at the Army Materials and Mechanics Research Center in Watertown, Massachusetts. These failures appear to be well understood, are often associated with fabrication defects (poor welds, braised joints, etc.), and the munitions in question have generally been removed from the inventory.

In broader terms, however, the question remains as to whether there is any urgency involved in the disposal of chemical munitions. Several points are important.

- There are not enough data to project the near- or long-term storage life of chemical agent containers. As mentioned above, the metallurgical testing has to date examined 105-mm and 155-mm leakers. There appears, for example, to be no basis for predicting the lifetime of M55 rockets or whether the incidence of failures might increase in the future.

- Corrosion appears to be a function of a chemical agent's rate of deterioration. Deterioration leads to changes in agent acidity, and purity. Hence, the presence of stabilizers or inhibitors to neutralize acid products and to prevent hydrolysis is essential. With regard to corrosivity, agents should be sampled periodically to determine their acidity, purity level (including dissolved gases such as oxygen), and ionic conductivity. SUPLECAM II appears designed to provide much of those data. SUPLECAM II should be modified, where necessary, to analyze all factors important to determine agent corrosion as a function of age.
- All munitions and containers subject to SUPLECAM II should be examined metallurgically as well through the stockpile test program in order to evaluate whether corrosion of the metal containers might have occurred. While some such investigations are ongoing, a systematic and coordinated study might allow the generation of kinetic models that could serve as the basis for reliable lifetime projections.

In terms of the container's metallurgy, there is surface corrosion on 1-ton containers that are stored outdoors, but it appears to be largely cosmetic and can be readily corrected. However, no information appears to be available on the condition of the inside surface, which is exposed to bulk agent. Moreover, it appears that brass plugs and valves had been installed on some of the otherwise carbon steel containers. Some of these have apparently deteriorated, because of galvanic corrosion, to the point where systematic replacement of the valves has had to occur. In addition, there are reports of leaks at the point where the sidewalls of the container are welded to the end caps, probably because of internal crevices. These problems may prove to be more difficult to manage.

4

Risk Analysis for Toxic Chemical Munitions

What is the magnitude of the risk to public health posed by toxic chemical munitions? The panel addressed this crucial question by first reviewing the risk calculations made by the Army and then developing its own qualitative analysis of the risk posed by toxic chemical munitions. The Army has calculated air concentrations and consequent human health impacts that might result from certain types of accidents, and the panel has found these calculations to be useful and appropriate as a first step in assessing the risk to public health and to the workforce at the storage sites. However, more comprehensive analysis is needed, including a broader range of situations where large quantities of toxic agents could be released into the environment and by using more accurate models for predicting air concentrations.

REVIEW OF ARMY RISK CALCULATIONS

The Army has a set of standard procedures for computing the area in which adverse health impacts are likely to occur following an accidental release of a toxic agent. The main calculation is the distance downwind at which 1 percent lethality will occur in an unprotected population. The basic reference for this calculation is the methodology for chemical hazard prediction (Department of Defense Explosives Safety Board, 1980).

The approach assumes the release of a given quantity of agent from an incident or accident. The maximum credible event is used as a worst-case release for planning purposes. Identification of the maximum credible event is done at each military base as part of that facility's planning process.

A standard type of Gaussian diffusion model is used to calculate air concentration of agent vapor as a function of distance downwind. The calculation depends on the atmospheric stability class and wind speed. Temperature is important in determining the amount of agent evaporated from a spill. The Gaussian model is a relatively simple and standard approach, which is widely used in computing the dispersion of atmospheric pollutants. Its use is appropriate for distances up to several kilometers where complex terrain effects are not significant.

Table 5 gives the concentration in mg-min/m^3 of agent corresponding to 1 percent lethality for nerve agents and a maximum level for no permanent skin injury for mustard agents (Department of Defense Explosives Safety Board, 1980). The toxicity values of the nerve agent are based on an adult breathing rate of 25 liters per minute, which corresponds to a moderate level of physical activity. The 1 percent lethality concentrations for children will be about one-third less than the values given in Table 5. Correction methods are suggested for small doses of GB and VX over extended time intervals and for percutaneous exposure to VX, which depends on the amount of clothing worn by the person exposed.

For explosive dissemination of mustard and VX, a different method is used to calculate the 1 percent lethality distance, since data are lacking on vapor and aerosol concentration of agent for the Gaussian model (Department of Defense Explosives Safety Board, 1980). Therefore, an empirical method, which is based on analysis of test data from Dugway Proving Ground, is used (Irving et al., 1970).

Depending on the atmospheric stability class (A-F), the 1 percent lethality distance for a ton of explosively disseminated VX is calculated to be from 4 to about 40 miles. Even 100 pounds of explosively disseminated VX could result in a 1 percent lethality under stability class F up to 10 miles downwind.

A handbook (U.S. Army, 1980) is available that calculates 1 percent lethality distances. It provides a guide to the input parameters needed and gives illustrative examples of the calculations. Field handbooks further describe how the calculations may be made on a TI-59 programmable calculator (Whitacre and Kneas, 1980), an Apple microcomputer (Whitacre, 1981), or as a FORTRAN program (Whitacre and Myirski, 1983). The 1 percent lethality calculations are usually made now on the TI-59 calculator.

As an example of a calculation, the panel asked the personnel at Umatilla to calculate the 1 percent lethality distance for a large spill of GB resulting from rupture of a 750-pound bomb. The assumptions for the calculation were as follows: 70°F temperature, 3 meters/second wind speed, stability class F, 25 percent of the agent in the bomb spilled, and 30 minutes elapsed until the spill was covered. (Umatilla personnel noted that a plastic sheet is kept in readiness when such munitions are handled and that 10 minutes is more realistic as the time needed to cover the spill.) The resulting 1 percent lethality distance was computed to be 200 meters.

TABLE 5 Toxicity Values (mg-min/m^3)

CHEMICAL AGENT	1% INCAPACITATION	1% LETHALITIES
BZ	31	N/A
GB	N/A	10
H, HD	N/A	150[a]
HT	N/A	75[a]
VX (Inhalation)	N/A	4.3

[a] Level corresponding to maximum exposure with no permanent skin injury rather than 1 percent lethality.

Thus, the 1 percent lethality distances are on the order of a kilometer or less, unless a large quantity of agent is explosively disseminated. How credible are such situations? The information from munitions testing by the Army is summarized in the Army's Handbook for Chemical Hazard Prediction (U.S. Army, 1980), which states that:

> In most planned munitions handling operations, it is not considered credible that explosion of more than one munition would occur in a single accident. Tests of several chemical munitions have shown that sympathetic detonation of the explosives does not occur in normal storage configurations for most items. The two exceptions are the M55 rocket and the M23 land mine.

The explosion of one land mine in a three-mine container might detonate the other two mines, but sympathetic detonation in other containers does not occur. For the M55 rocket, however, a series of sympathetic detonations could spread through the rockets stored in an igloo. Tests were conducted at the Black Hills Army Depot in South Dakota and at Dugway Proving Ground, in which such propagation occurred.

While 97 percent of the agent in the exploding munitions was destroyed by the high temperature in the resulting fire, an estimated 570 pounds of GB was released (Irving et al., 1970). For VX-filled M55 rockets, an estimated 37 pounds of agent was released. Most of the agent was released in the first 15 to 20 minutes following the initial explosion, although the munitions in the igloo continued to burn and explode for several hours.

The Army uses the explosion of an igloo containing GB-filled M55 rockets as the basis for the maximum credible event at five of the eight sites (Lloyd, 1984). The results of the Army's calculations are summarized in Table 6. For the five sites in which the maximum credible event is based on the M55 rocket explosion, the 1 percent lethality distance was computed to be up to 7-8 km (4.5 to 5.2 miles) under daytime conditions and up to 27 miles (43 km) at night, when the height of the mixing layer is much lower. The 1 percent lethality distance for the other three sites is less than a kilometer for Edgewood (where few if any agent-filled munitions are stored) and less than 100 meters for Newport and Pueblo.

There are considerable uncertainties in these calculations that are not apparent in the Army's summary (Lloyd, 1984). First, the estimated release, 2.52 percent of the GB contained in an igloo filled with M55 rockets, is based on a small amount of field test data. Under slightly altered conditions, much less of the agent might be destroyed by the high heat in the igloo, so the release would be much larger than the 2.52 percent that the Army has assumed (Lloyd, 1984). A wide variety of circumstances could influence the amounts and emission rates of GB and VX from fires in igloos containing M55 rockets (Irving et al., 1970, p. 79).

Second, the Gaussian dispersion model used by the Army cannot assess concentrations more than a few kilometers from where the release took place, especially where mountains, water, or other terrain features affect wind patterns. The Army's calculation should be taken as an order-of-magnitude estimate only for the 1 percent lethality distance for large explosive releases. A more detailed model, including terrain effects, could give a significantly improved prediction of the air concentrations 5 to 30 miles downwind that could result from the explosion of an igloo containing GB-filled M55 rockets.

TABLE 6 One Percent Lethality Distances Calculated by the Army for Maximum Credible Events at the Eight U.S. TCM Storage Locations (Lloyd, 1984)

MCE	DAYTIME CONDITIONS	NIGHTTIME CONDITIONS
GB-filled M55 rocket explosion (2,000 rockets in igloo, 2.52% of agent released)		
Anniston	7.3 km (4.5 miles)	43.2 km (26.8 miles)
Lexington Blue Grass Army Depot	7.3 km (4.5 miles)	36.3 km (22.5 miles)
Pine Bluff Arsenal	7.3 km (4.5 miles)	43.2 km (27 miles)
Tooele Army Depot	7.8 km (4.8 miles)	43.2 km (27 miles)
Umatilla Army Depot Activity	8.3 km (5.2 miles)	43.2 km (27 miles)
Other MCEs		
Edgewood: detonation of 155 mm GB round	0.945 km = 3,100 feet	
Newport: rupture of 1-ton container of VX	less than 25 meters = 80 feet	
Pueblo: detonation of 155 mm HD round	80 meters = 262 feet	

The Lawrence Livermore National Laboratory in Livermore, California, has developed the Atmospheric Release Advisory Capability (ARAC) system (Dickerson et al., 1983) for the Department of Energy (DOE) and the Defense Nuclear Agency (DNA). It calculates the air concentration and ground contamination from airborne releases of radioactive materials. ARAC uses both a simple Gaussian model for rapid calculations and a detailed, three-dimensional numerical flow model. The latter requires up to 45 minutes of computer time, but this model provides site specific calculations that include the effects of complex terrain and available meterological data from the site.

The Lawrence Livermore National Laboratory has made an extensive investment in both models and in the capability to communicate rapidly to the affected site. ARAC is being extended to provide emergency response planning capability to 45 DOD sites. The adoption of ARAC would appear to be an excellent way for the Army to upgrade its capability to analyze the potential consequences for large-scale releases, such as an M55 rocket explosion in an igloo.

Third, other credible release scenarios have apparently not been evaluated. Airplane crashes, earthquakes, lightning strikes, forest fires, and acts of terrorism or sabotage could cause munitions or agent containers to rupture or explode. This could result in 1 percent lethality distances comparable to those for the explosion of an igloo of M55 rockets. Even if the probability for such events to initiate a large-scale release is extremely small, the consequences for public health are potentially very great. A risk assessment should be carried out as soon as possible for a full range of natural disasters and terrorist acts that could initiate a large release of agent and threaten public health in the vicinity of the eight Army storage depots.

QUALITATIVE ANALYSIS OF RISK

In assessing risk from storing chemical munitions, it is useful to distinguish several different kinds of events that could initiate an accident or incident threatening public health: storage, routine operations, and extraordinary situations such as a terrorist attack or an airplane crash.

The first concern is leaking munitions or agent containers. Are such leaks becoming more frequent because of corrosion or deterioration as the munitions and containers age, and do such leaks threaten significant adverse consequences to public health?

While there is still considerable uncertainty about deterioration over time, the available information indicates that the frequency of leaks for most munitions has not substantially increased in recent years. Further, most leaks have been small and increasingly sensitive detection methods may be responsible for some of the recently identified leakers. The small number of munitions that do leak are stored in airtight cannisters until they can be disposed of.

The exception is the M55 rocket. A large number of M55s have been found to leak in recent years. Even for these munitions, however, the appearance of leakers in storage appears to have a low probability of affecting public health. The leaking munitions can be detected, put into containers as an interim measure, and ultimately disposed of.

The second class of events of concern is that of incidents or accidents occurring during routine operations such as inspection, moving munitions or agent containers on site, uploading/downloading, and disposal. The Army generally carries out such operations with extreme care; incidents and accidents involving even very small releases of agent have been rare. However, there have been several instances in which Army safety practices could be improved. In the case where a single munition detonates or a container is ruptured, the area in which serious adverse impacts on health could occur is confined to the base, and personnel with gas masks and protective clothing are prepared to undertake a rapid decontamination and clean-up operation.

Again, there are exceptions. First, as described above, an explosion of one M55 rocket in an igloo could trigger a large release that could jeopardize public health in locations 5 to 30 miles downwind. Handling of M55 rockets should be carried out with extreme care, especially in igloos or other confined spaces where detonation of one rocket could cause the explosion of others nearby.

The third class of events is where an agent might be disseminated as a result of an explosion caused by a large and sophisticated terrorist group, a natural disaster such as an earthquake, tornado, forest fire, or an airplane crash directly on a storage site. The panel has no information indicating that the Army has carried out a risk analysis for such events, but it seems clear from their hazard calculation methodology that such events could cause large numbers of fatalities in populated areas up to tens of miles downwind from the storage location.

The Army should assess carefully the probability and potential consequences of a comprehensive set of such extreme release scenarios. The Army should also evaluate measures to reduce the probability of the initiating event, the quantity of agent released, and the magnitude of the consequences. Measures to be evaluated should include increased security protection, restriction of air traffic over chemical storage locations, removal of bulk agent from above-ground storage into earth-covered igloos, acceleration of disposal programs, and increased planning for emergency evacuation of nearby communities.

5

Army Operations With Respect to Toxic Chemical Munitions

Basically, the Army seeks to maintain a reliable, deterrent stockpile of toxic chemical munitions in a safe and secure manner. Although there are numerous Army units involved with chemical munitions and agents, this report deals only with those for whom toxic weapons are a major part of their mission. The Army's organization for this effort is complex, but their operations appear to have been successful. Those involved in research, development, and logistics appear to be responsible and follow existing directives.

Nevertheless, improvements can be made and concerns as to efficiencies do and will continue to exist. The Army's greatest problem, in fact, may be taking past successes for granted. But the Army's mission of maintaining the stockpile is generally being achieved.

The United States Army Materiel Development and Readiness Command (DARCOM) is responsible for managing the toxic weapons stockpile. This includes testing, surveillance, supply, maintenance, and disposal. DARCOM's Chemical and Nuclear Office, an organization of seven people, coordinates the management of chemical weapons with other DARCOM and Army offices. The three field operating agencies guide and direct DARCOM's subordinate commands involved in managing toxic materials. The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) is responsible for all aspects of the disposal program, including chemical surety matters. The DARCOM Field Safety Activity provides services, training, and evaluation of safety matters. And the Surety Field Office ensures compliance with the chemical surety program requirements through inspections.

All are effective organizations. However, the DARCOM Chemical and Nuclear Office appears to be inadequately staffed to maintain cognizance of field operations as well as provide advice on chemical munitions matters to the DARCOM commander and staff. Given that management operations are decentralized to the major subordinate commands, the sensitivity and critical nature of chemical munitions operations should have greater visibility at headquarters.

DARCOM has two major subordinate command organizations that are directly involved in chemical weapons: the Armament, Munitions and Chemical Command (AMCCOM) and the Depot Systems Command (DESCOM). AMCCOM, which is responsible for the overall management of toxic chemical munitions, provides guidance to the DESCOM depots (Anniston, Lexington-Bluegrass, Pueblo, Tooele, and Umatilla) for their supply, maintenance, and surveillance activities. This same attention was provided to Pine Bluff Arsenal, the Chemical R&D Center at Edgewood, and Newport. Communication and coordination between these two organizations and their subordinate commands appeared to be good. Although time to visit the eight sites was limited, few problems surfaced to challenge the responsiveness and competency of these organizations to conduct operations.

However, the panel is concerned that reductions in available resources could impair the effectiveness of AMCCOM management efforts and the coordination of Army organizations with responsibilities for toxic chemical munitions. The organizational structure available for chemical munitions operations at the eight depots appears to be adequate for accidents involving small quantities of agent, with some elasticity for implementation of the Chemical Accident/Incident Control plan (CAIC). Obviously a massive exercise could test the adequacy of the existing organizational structure in command-control, security, medical, etc. The impact of an event resulting from such a threat should be evaluated as soon as possible.

Although there were similarities in chemical surety operations and organizations at the eight depots, each depot also had unique aspects. There could be greater standardization, since the depth of responsiveness to requirements varied. For example, all security organizations conducted threat training, but not all had taken the initiative to have professional instruction provided by the Military Police School at Fort Gordon, Georgia. In another example, the medical personnel had varying amounts of training, for which the timeliness varied. This does not indicate that AMCCOM, DESCOM, and other Army elements are not carrying out their mission, but rather that their staffing could be improved and that standardization could increase operational effectiveness.

Some panel members felt that an evaluation should be made to determine if the organizational staffing in the area of command and control is adequate at Anniston and Tooele depots for CAIC operations. Both commands are responsible for their own large management activities and also for their subordinate installations. The parent organizations may not have adequate manning to guide their subordinate activities.

Two operational programs further indicate that the current organizational structure is adequate to manage the toxic chemical munitions stockpile. First, the Drill and Transfer System (DATS) has already successfully been carried out at five chemical munition installations and will operate for several more years. Importantly, DATS has involved cooperation and positive actions between several major subordinate commands as well as DARCOM headquarters.

The Surveillance Program, Lethal Chemical Agents and Munitions (SUPLECAM), is the other successful operation. Fifty lots were sampled in the first cycle and a second cycle is under way--all without incident. Although the DARCOM organizations competently supported this program, some question exists as to the necessity of training teams on SUPLECAM operations at each site. Safety and effectiveness might be improved if a single team were moved from depot to depot, avoiding the need to train multiple teams for different installations.

In summary, DARCOM appears to be organized adequately to successfully manage toxic chemical munitions operations. The panel believes that these command and control plus operational organizations should perform satisfactorily in the future. It bears repeating, however, that to assure more effective management for DARCOM, the personnel of the Chemical and Nuclear Office at DARCOM headquarters should be strengthened. Also, the current organizations for CAIC operations should be tested with realistic exercises involving terrorist operations, preferably using Army personnel outside DARCOM experienced in such tactics.

6

Medical Aspects

MEDICAL SUPPORT OF THE CHEMICAL MISSION

Most depots have a medical unit that is responsible for general health care. Their responsibility is for employees and their dependents, armed forces personnel, some retirees , and, in some cases, those in the area eligible for veterans' benefits. In general, the involvement of medical personnel in the chemical mission of the depot seems to be regarded as a secondary aspect of their responsibilities. In part, this is because of the organizational structure in which the medical officer reports to the medical command at another site, often a regional Army hospital where the problems associated with chemical agents do not necessarily have high visibility.

The secondary nature of the chemical mission is manifested in various ways. For example, many medical officers apparently lack specific previous training in dealing with toxic chemicals. This is subsequently provided, but on an inconsistent schedule. In addition, there is no overlap of medical personnel; incoming physicians and nurses do not learn from those whom they are replacing.

Moreover, there seems to be an inadequate body of reference material or guides regarding the medical aspects of chemical agents. In at least one case, a physician responded by personally amassing what was reported to be a comprehensive array of material that would be of general use to physicians with similar responsibilities.

It is not altogether clear that the medical personnel are well integrated into the Chemical Accident/Incident Control (CAIC) procedures at all depots, particularly in this capacity as liaison with civilian medical services outside the depot that would be involved in dealing with an accident or incident of any scale. At some depots, planning for such events has been handled well, but this is probably more due to the concerns and interests of the particular officers involved than to a broadly implemented policy. Liaison with hospitals, clinics, and physicians in the community is important because on-base medical facilities and equipment, although adequate for routine activities, may not be sufficient in case of either a serious accident or incident.

Some depots may depend on community resources to an even greater degree since, in addition to the inexperience or lack of training of the medical officer, the support personnel assigned to the medical contingent appear to lack the background, experience, and special training needed to treat victims exposed to chemical agents.

MEDICAL RESPONSIBILITIES RELATED TO PERSONNEL STATUS

Medical personnel at the depots are involved in various aspects of the physical and mental health of employees and armed forces personnel. This role extends beyond those working with chemical munitions. Myriad Army regulations hamper efforts to deal medically with mental instability, drug or alcohol abuse, or poor physical condition. Still, there appears to be scope for a more uniform and aggressive policy to deal with these problems among employees assigned to chemical security and surety.

For example, the ability to function effectively in class A protective gear in the heat of the summer is very limited at most depots. Circumstances can arise in which employees in poor physical condition would be unable to cope adequately with a chemical accident or incident and would be placed at high personal risk while doing so. Age must also be considered a factor in this context; a workforce with balanced physical abilities would seem necessary at the potential expense of strict seniority rules.

Similar problems arise with regard to substance abuse or mental instability as they relate to accident or incident response, or simply to access to chemical munitions. Although there is a program for screening and monitoring personnel involved in chemical security and surety, a more effective collaboration is needed between the medical officer, the personnel department, and the command to ensure prompt reassignment of problem employees.

In general, most of the problems outlined above are amenable to straightforward solution. Priority should be given, for example, to the selection of properly qualified medical personnel who are then properly trained in dealing with the consequences of working with toxic chemicals prior to their assignment to the depots. Moreover, it seems sensible to overlap the tours of duty of medical officers and their replacements to ensure an acceptable level of CAIC readiness. Each medical contingent should have adequate reference material to consult on how to treat chemical injuries. If these are not currently available, they should be prepared and disseminated promptly.

It is somewhat more difficult to raise the priority of the chemical mission among the Army medical community generally because it is a readiness issue rather than one of day-to-day involvement. Perhaps this could be done by involving medical personnel in periodic conferences with the depot commander and the security and surety personnel to air problems of mutual concern as well as to expose the latter to the broader aspects of the depot's chemical mission. An early subject of such meetings might be the establishment of an ongoing relationship between depot medical personnel and their counterparts in the civilian community. This would help develop integrated CAIC plans for those depots that do not currently have them.

7

Security

Security at the eight chemical munition storage depots is governed by Army Regulation AR 50-6, Supplement 1 to AR 50-6, and other site-specific supplements. These regulations attempt to ensure security of the stockpile and to minimize the risk of a security breach from civilian employees.

The depots all have adequate basic security, but it could be improved. Some exclusion areas have second gates with substantially less security than at the main gate. Basic security seems adequate for conventional threats, and the depots seem to be improving their defenses.

However, the security procedures are clearly not adequate to stop a large and sophisticated armed force. Breaching a facility's security perimeter does not, fortunately, give access to the igloos, nor is it easy to do anything serious to the munitions (except perhaps the M55 rockets) even if access is obtained. Still, the munitions, particularly those located at facilities close to populated areas, will continue to be a potential target. To obtain the level of security necessary to prevent intrusions would require substantial increases in effort and costs.

Security also involves a personnel reliability program that is part of chemical surety. Most of the facilities are run by civilians with minimal military presence (though the ratio of military to civilian personnel varies considerably by site). The isolation of the facilities and the importance of these storage areas to the local economy has produced a loyal workforce with a low turnover rate. These desirable conditions lead to at least the suspicion that informal structures and networks may be more influential than the formal organizational structure on which the chemical surety program is founded.

It is possible, for example, to imagine circumstances in which workers might cover up for each other. Given that, it is certainly not possible to rule out an internal security threat.

Finally, it is questionable whether the depots possess the emergency capability to respond to an accident that releases large amounts of agent. Emergency plans appear to be designed to handle a relatively modest, industrial-sized accident. An aircraft crash into an igloo, an explosion in a bulk storage area, or the ignition of an igloo of rockets could all create havoc. Emergencies either in very hot weather (when protective clothing can only be used for a limited time) or at night could require more trained personnel than would be available.

The security of these facilities has been adequate by the standards of the 1970s. One can not be sanguine that this level of security will continue to be adequate in the 1988s and 1990s. The limited emergency capability of the smaller storage depots in particular, makes them appropriate targets for either consolidation with munitions at larger depots (particularly Tooele) or for disposal efforts.

8

Legal Aspects of Toxic Chemical Munitions

Only two federal laws specifically govern the storage of toxic chemical munitions: the Armed Forces Appropriation Acts of 1969 (PL 91-121) and of 1970 (PL 91-441). In 1978, however, President Jimmy Carter signed Executive Order 12088 requiring all federal agencies, including the Army, to comply with all U.S. environmental laws.

The appropriations acts of 1969 and 1970 require that the Department of Health and Human Services review any proposed movement, outside of an Army base, of toxic chemicals or munitions of more than one liter and recommend measures to protect public health and safety. Congress and the governor of the state must be notified 30 days before the action may be implemented. In addition, the Department of Defense Explosives Safety Board (DDESB) must review the project before it can be approved by the Department of Defense.

Since storing an aging collection of munitions in guarded facilities with no intention to release them to the environment is essentially a passive function, the legal problems are minimal. There appear to be no state or local laws applicable to storage. During inspection, maintenance, and other routine operations involving handling of the stockpile, however, legal requirements will apply. But meeting these requirements should cause little difficulty.

The relevant laws include the National Environmental Policy Act, the Clean Air Act, the Clean Water Act, the Comprehensive Environmental Response, Compensation, and Liability Act, the Toxic Substances Act, the Occupational Safety and Health Act; and the Hazardous Materials Transportation Act (see Appendix E).

The National Environmental Policy Act (PL-190) of 1969 (NEPA) requires environmental impact statements for all major actions that could significantly affect the environment. NEPA also created the Council on Environmental Quality (CEQ), which issues regulations for the implementation of the statute. Under the authority of these regulations, since 1978, the Environmental Protection Agency (EPA) has primary responsibility for the review of environmental impact statements.

The Clean Air Act (PL 95-95) of 1977 authorizes EPA to set air quality standards and to review state plans to implement them. Similarly, the Clean Water Act (PL 95-217) of 1977 requires EPA to set criteria for the discharge of pollutants into the nation's waterways.

The Safe Drinking Water Act (PL 95-523) of 1974 authorizes EPA to set standards for drinking water, but allocates primary enforcement responsibility to the states, with EPA taking an advisory role in enforcement.

The Resource Conservation and Recovery Act (PL 94-580) of 1976 establishes guidelines for solid and hazardous waste management. The standards apply to the generation, storage, transportation, and disposal of any hazardous material. Under the law, EPA regulations permit the exclusion from regulation of hazardous wastes that, when mixed with water or other wastes, contain concentrations no greater than 1 to 25 ppm.

The Comprehensive Environmental Response, Compensation, and Liability Act (PL 95-510) of 1980, popularly known as "Superfund," provides that any person, company, or government agency that operates a hazardous waste site shall be responsible for its cleanup and for damages to natural resources. The law authorizes EPA to clean up hazardous waste sites and to seek reimbursement for the costs from those responsible for the site.

The Toxic Substances Control Act (PL 94-469) of 1976 requires testing and regulation of potentially toxic chemicals before they are manufactured. The law provides for regulating the production, use, distribution, and disposal of toxic substances and requires manufacturers to notify EPA before a potentially toxic substance is made.

The Marine Protection, Research, and Sanctuaries Act (PL 92-532) of 1972 prohibits the dumping of any radiological chemicals and biological warfare agents into ocean waters except by permit granted by EPA. The act specifically says that no permit shall be issued for dumping chemicals intended to be used in war.

The Occupational Safety and Health Act (PL 92-596) of 1970 sets limits on the level of potentially dangerous chemicals that workers can be exposed to. The limits ate published annually by the American Conference of Governmental Industrial Hygienists.

The Hazardous Materials Transportation Act (PL 93-633) of 1974 authorizes the U.S. Department of Transportation (DOT) to designate particular quantities and forms of materials as hazardous, issue regulations for their safe movement, establish a règister of those authorized to transport hazardous materials, and make exemptions to the above, if appropriate.

Additionally, U.S. Army regulations and memoranda have addressed responsibilities and procedures for storing, transporting, and disposing of chemical and biological munitions under the above-mentioned laws and amendments. Army Regulation 200-10, in particular, explains the Army's environmental program and assigns responsibilities for its management, including chemical and biological munitions.

Finally, it is important to realize that laws and regulations represent the best judgment of the responsible parties at the time they are implemented. As conditions change (e.g., new knowledge, technological advances, different values, emergency conditions, or national interests) these laws and regulations are subject to change. However, the committee makes no such proposals at this time.

Executive Order 12088 provides for waivers for these laws in cases of national emergency. To date, however, the Army has not requested waivers for the storage or handling of toxic chemicals. These federal laws normally apply only to regulations setting standards for a specific chemical pollutant. There are no EPA standards for chemical agents, nor are there likely to be any in the foreseeable future. State and local governments, with very limited personnel and budgets and with no expertise in handling chemical agents, are unlikely to play much of a role in protecting the public from these materials.

Public confidence might be increased, however, if environmental standards were to be set by an entity in the Department of Defense that is separate from the U.S. Army Material and Readiness Command (DARCOM), which is responsible for meeting the standards at the sites it administers. Site monitoring might also be separated from DARCOM's responsibility.

LEGAL ASPECTS OF SPECIFIC PROGRAMS

Under the Drill and Transfer System (DATS), unserviceable munitions are drilled in a glove box device and the chemical agent is transferred to a bulk container. An elaborate system of monitoring is used to ensure that no chemical agent is released to the environment. Since DATS contains all vapors, as specified by the Toxic Chemical Hazards or Combined Toxic and Explosive Hazards Safety Standards, it meets the requirements of the applicable air pollution laws. Some very localized air pollution may be caused by the demolition of explosives at the end of the operation. These actions should not degrade air quality or present legal problems.

Although brine solutions are used in DATS for decontamination, the system is designed for total containment, including spills. The brine streams will, presumably, never be released to U.S. waters because they are evaporated in a special facility at Tooele. Thus, DATS complies with federal and state water pollution laws.

The brines will presumably be subject to the hazardous waste management provisions of the Resources Conservation and Recovery Act (RCRA). Complying with RCRA should present no problems for the Army. The munition casing can be treated as material subject to RCRA or be cleaned and treated as a nonhazardous waste. In the past, the brines have been shipped by truck to the Chemical Agent Munitions Disposal System (CAMDS) facility at Tooele, where they were processed through the drum drying facility.

The major problem is likely to be the newness of these requirements. For example, the Pine Bluff Arsenal recently obtained a RCRA permit for disposing of hazardous material (unrelated to storing chemical munitions). It took considerable efforts to compile the required information, but the permit was granted--the first such permit granted by the state of Arkansas under federal law.

The brines have been classified in accordance with DOT regulations as "corrosive liquids, not otherwise specified." The containers used have liners. Each container is marked with a "corrosive" label and the vehicle in which it is shipped displays "corrosive" placards in accordance with DOT regulations, as required by law. This action is subject to the provisions of the Armed Forces Appropriations Acts of 1969 and 1970.

Because the Surveillance Program, Lethal Chemical Agents and Munitions (SUPLECAM) uses a process somewhat similar to DATS, its legal problems seem to be the same as those already discussed. CAMDS is the most elaborate, currently operational disposal facility. This facility has been safely operating since 1979. Located at the Tooele Army Depot in Utah, it is subject to limits on its emission to the air and its residuals are subject to RCRA requirements. Moreover, the final environmental impact statement for CAMDS operations was prepared in March 1977. As far as is known, the facility is in compliance (see Chapter 12 for more information) with all federal environmental laws and regulations.

9

Stockpile Assessment Panel Findings, Conclusions, and Recommendations

Despite the massive quantities of toxic chemical agents and munitions in the U.S. stockpile, the absence of any significant accident and the occurrence of only a few minor incidents attest to the efficacy of Army operations in managing its toxic chemical inventory.

Thus, the Stockpile Assessment Panel concludes that:

- The Army is competently managing the task of preserving the toxic chemical stockpile within the limitations imposed by each depot's location and by applicable statutes and Department of Defense (DOD) regulations. Further, the management of the various depots seems to conform with relevant Army regulations and procedures.

Nevertheless, there are a number of areas or situations in which improvements could be made.

RECOMMENDATION 1:

Since the auditing responsibility should be separated from line responsibility, the responsibility for setting environmental standards for toxic chemical agents and munitions should continue to reside in a DOD entity completely removed from the U.S. Army Material Development and Readiness Command (DARCOM) chain of command.

RECOMMENDATION 2:

The responsibility for auditing environmental monitoring, whether for storage or disposal, should likewise be separated from DARCOM's responsibilities.

At the present time, the Army monitors the possible leaking munitions on a regular basis only by perimeter detectors or intermittently at the time that igloos are opened for inventory or other routine inspection. New methods exist that permit continuous monitoring of the vents from each individual igloo. This would be advantageous both with respect to early detection of new leakers and with respect to the safety of those who have to enter igloos for inventory, inspection, or other purposes.

RECOMMENDATION 3:

> Continuous remote monitoring of each igloo's exhaust vents should be considered for installation as soon as is reasonably possible. Earliest attention should be given to those igloos containing M55 rockets.

RECOMMENDATION 4:

> There is still inadequate information on the cause of leaks in munitions and their probable rate of occurrence over time. Therefore, a permanent record should be maintained of emissions observed to occur at each storage site. This record should be kept at a single location.

RECOMMENDATION 5:

> Work should be continued and expanded to elucidate the chemical and physical processes that might compromise the metallurgical integrity of chemical munitions during prolonged storage.

The number of such leakers discovered each year has been small relative to the number of munitions and containers in storage. Nevertheless, they occur in significant numbers. Many of these leakers seem to occur at random, although occasionally an entire production lot can be identified as particularly prone to leakage. The latter may then be segregated for extra careful supervision.

An examination of the data concerning the number of such leakers discovered in recent years indicates that:

- o There is no present evidence of a trend that would indicate an increasing rate of deterioration of toxic chemical munitions.

However, in addition to visible evidence of corrosion, there is no reliable data on the possible progressive decomposition of agent and/or accompanying inhibitor with time. Therefore,

- o It is not possible to give assurance at this time that an increased rate of deterioration may not occur within the relatively near future.

Relative to the number of munitions of a given type in storage, it is evident, however, that:

- o Leakers occur more frequently among M55 rockets than in the other munitions in storage.

Since the leaking munitions can be detected at an early stage, identified, contained, and ultimately disposed of, leakers appear to have a low probability of affecting public health.

- o Leakers are handled competently to prevent them from becoming a life-threatening hazard to off-site civilian populations.

A different kind of threatening accident or incident can occur during on-site handling or movement of toxic munitions. Quite properly, most such handling is minimized even when it is unavoidable as in, for example, inventory procedures or in the search for a leaker known to be within an igloo. There were examples witnessed, however, where safety precautions seemed not to be observed as stringently as was reasonably possible. In particular,

- o Some toxic munitions in storage were being "uploaded" to full serviceable status by adding bursters under conditions for which safety could have been improved.

The panel further noted that:

- o Uploaded munitions make any disposal process much more expensive and dangerous than would have been the case before uploading because of the inherently higher risk and cost.

RECOMMENDATION 6:

Uploading should be minimized or, if possible, discontinued.

A further area of important concern is that the materials are physically secure, both from external and internal intrusion.

- o Each facility has adequate base security for conventional threats. Furthermore, even during the period of this committee's inspections, continuing improvements in security have been noticeable.

The nature of the work force at each depot is important. Although there are some significant variations,

- o Most facilities are run by civilians with minimal military presence. Furthermore, the work force has a relatively low turnover rate.

Most of the observed sites benefit from a stable and experienced civilian staff. On the other hand, revitalization through persistent recruitment and organizational change appears desirable to sharpen performance.

RECOMMENDATION 7:

> Personnel policies should be reexamined at each depot to ensure that the respective work forces have the appropriate experience that comes from stability, on the one hand, and revitalization that comes from new employees on the other.

The situation at Newport is unusual since the storage there is under contractor management. Because changes in procedures may require renewed negotiations, Newport's management may be less responsive to timely changes thought to be necessary.

RECOMMENDATION 8:

> The storage of toxic chemical agents at Newport, therefore, should be removed from contractor control and made the direct responsibility of the Army as at other depots.

During site visits in various locations, panel members observed handling of toxic chemical munitions under conditions for which safety precautions could have been improved. In particular, during the handling of M55 rockets, fork lifts were used in a manner that was not as safe as it might have been. On another occasion, too many people seemed to be present during dangerous parts of SUPLECAM operations. In addition, uploading operations in which bursters were being inserted in munitions already loaded with agent seemed to lack maximum care expected in such activities.

RECOMMENDATION 9:

> Personnel who handle chemical agents and munitions should be reminded periodically of the importance of adhering to maximum safety precautions. Established procedures should be reexamined to make sure they include optimum safety considerations.

DESIGNING MUNITIONS FOR EVENTUAL DISPOSAL

When toxic chemical agents were first designed and manufactured, too little attention was given to the likely problems that would result from trying to dispose of them when they were no longer needed.

RECOMMENDATION 10:

> An integral part of the planning for and cost considerations of a toxic munitions stockpile should be the cost of its eventual safe disposal and the time frame for so doing. Safety must always be the primary consideration above cost.

In fact, part of the costs to society of any munition are those of its disposal. In the case of toxic chemical munitions, the disposal costs may be large compared to those of deployment. Therefore,

RECOMMENDATION 11:

> Any new toxic chemical munition should include, as an integral part of its design and manufacture, plans for its storage, monitoring, and eventual disposal. Furthermore, these plans should include recommended processes for safe and effective disposal. These plans should be updated on a regular schedule.

MAXIMUM CREDIBLE EVENT

The Army has procedures for computing the area in which adverse health effects may occur following release of a quantity of toxic agent. The result of the main calculation is the distance downwind at which 1 percent lethality will occur in an unprotected population. The approach requires the formulation of a hypothetical "maximum credible event," which is conceived to be the worst case release of a toxic agent that is reasonably possible given the site specific details of agent storage. The specification of maximum credible events is done at each base in the facility planning process.

- o Each Army base with a stockpile of toxic chemical munitions has defined a maximum credible event and has developed plans to respond to it.

Although a given site may have prevailing winds in certain directions, it is possible that at some given time the wind may come from any direction. The plans to respond to a maximum credible event, therefore, encompass the possibility of response within a radius that is calculated as the 1 percent lethality distance.

The estimates of potential hazards using the present maximum credible events are based on dispersion models of chemical agent in the atmosphere, which do not use the best current technology. For events involving large-scale releases, such as from M55 rocket explosions, the calculations should be obtained from better dispersion models that use detailed weather information and incorporate complex terrain effects. Such models have been developed under Department of Energy sponsorship at the Lawrence Livermore National Laboratory, and DOD has selected these models to support contingency planning and emergency response operations at bases where nuclear materials are stored (Dickerson _et al_., 1983).

RECOMMENDATION 12:

The Army should evaluate the usefulness of the Lawrence Livermore National Laboratory's Atmospheric Release Advisory Capability (ARAC) models as a means of improving its capability to assess and plan for maximum credible events involving large-scale releases.

The plans at a given site for controlling chemical accidents and incidents depend critically on the choice of an appropriate maximum credible event scenario. In considering the maximum credible event chosen for each individual site,

- Other reasonably credible scenarios can be imagined that would involve agent releases in quantities considerably larger than those assumed in a number of the current maximum credible events. These scenarios include airplane crashes or sabotage by determined intruders.

These same changing perceptions of the dangers of either sabotage or terrorist activities and of known natural disasters dictate similar renewed attention to plans for controlling chemical accidents and incidents.

RECOMMENDATION 13:

The general plans for each depot's response to potential terrorist attacks on chemical exclusion areas should be reviewed as soon as possible. The plans should be strengthened to provide an adequate response to such potential incidents.

The following four recommendations relate to the possibility of such extreme scenarios.

RECOMMENDATION 14:

An evaluation should be made to determine if the organizational staffing and equipment available in time of emergency is adequate to control potential accidents or incidents.

At several depots, plans require coordination with and dependence on civilian emergency forces from communities outside the respective bases.

RECOMMENDATION 15:

Plans should be reviewed to ensure that they adequately provide for cooperation with community emergency forces. Particular attention should be paid to communication capabilities, to the provision of adequate equipment off site, and to the training of such units in emergency procedures.

RECOMMENDATION 16:

Army regulations should be reviewed to assess their adequacy to protect against sabotage, theft, and other breaches of security from internal as well as external sources.

The fully protective suiting required in emergencies demands extreme physical conditioning on the part of the wearers, especially in hot climates within which many storage depots are located. No evidence was observed that physical conditioning was a consideration in the emergency plans at each depot.

RECOMMENDATION 17:

Physical conditioning on the part of those who work with toxic chemical munitions should be required as part of the plans for dealing with emergencies.

RELATIVE DISPOSAL PRIORITIES

The Army needs to assess the probability and consequences to public health of possible events believed to be of very low probability. This involves an analysis of the risk to sizeable populations within the area where a toxic agent might be dispersed of in lethal quantities.

- o Large populations are included within the 1 percent lethality distance for a number of the storage depots, including all that store M55 rockets.

RECOMMENDATION 18:

Special attention should be given to those cases in which the maximum credible event includes sizeable civilian populations. Disposal should proceed as rapidly as possible for agents or munitions that place civilian populations at risk.

Review of sample calculations shows that the 1 percent lethality distances are at the order of a kilometer or less unless the quantity of agent dispersed were large, as, for example, in an explosive dissemination. Army reports based on field tests indicate that, with the exception of the M55 rocket and the M23 land mine, the explosion of a single munition in an accident under normal storage conditions would not propagate to other similar munitions in the same igloo. In such single detonations, the release of toxic agent is not anticipated to be large.

In the case of M23 land mines, the explosion of one mine in a three-mine container might detonate the other two mines, but further detonation would not occur. For the M55 rocket, however, tests demonstrate that a series of detonations could spread to all rockets stored in a single igloo.

- There is a demonstrated possibility that the explosion of a single M55 rocket could cause other rockets in the same igloo to explode, a process that could greatly increase the quantity of agent potentially released by a single explosion.

The M55 rockets stored at a number of locations, therefore, represent a special problem. First, they constitute a large fraction of leakers. Second, they are especially dangerous since they are stored with bursters, propellants, and agent in place.

RECOMMENDATION 19:

The Army should give first priority be to disposal of the M55 rockets wherever they are located. This recommendation cannot be stated too strongly.

The committee accepts the conclusion of the Army that:

- There is no indication that explosions of individual artillery shells could propagate to other similar items under the conditions of storage within a given igloo.

Turning to the stocks of bulk agents, the committee notes that:

- Some 60 percent of the toxic chemical materials are stored as bulk agent, which is not militarily useable until it is loaded into munitions.

The Newport depot contains equipment for loading toxic chemicals into munitions. That equipment has not, however, been used for more than 15 years. Moreover, it is maintained by a single knowledgeable employee nearing retirement age. It is very doubtful that this plant could be made to operate quickly in case of an emergency. It would be faster and less expensive to build a new facility than to use what is available at Newport in such a situation.

- There exists no presently operable facility for loading toxic chemical agents from bulk containers into munitions in the United States.
- The time required to synthesize new bulk agent is likely to be less than the time required to build a plant to load such agent into munitions.

This is a relevant consideration in ascertaining the benefits accruing from retention of the bulk agents currently in the stockpile compared to the dangers of that retention. Even under the best conditions, storage always has some risks. It is very likely that new toxic chemical agents can, in an emergency, be synthesized and loaded into munitions at least as fast as current bulk stocks can be brought to the same deliverable condition.

RECOMMENDATION 20:

> Precise time schedules should therefore be determined for synthesizing bulk toxic chemicals in an emergency and for loading them into deliverable munitions.

RECOMMENDATION 21:

> If the panel's conclusion is indeed verified, bulk stocks of toxic chemical agents should no longer be maintained. Present stocks should be disposed of as soon as reasonably possible.

Disposal might be less expensive and faster if the current stocks are consolidated at fewer locations. Despite the risks associated with transportation, it may be safer to move the stocks to locations permitting earlier disposal than to preserve them for extended periods in storage at locations where off-site populations are at risk.

RECOMMENDATION 22:

> A thorough review should be undertaken of the possibility of transporting toxic chemical munitions and agents to safer locations while awaiting disposal.

RECOMMENDATION 23:

> If disposal should be postponed for any significant period of time or abandoned because of changed conditions, the Army should consider selectively consolidating its eight storage depots, consistent with strategic military considerations.

The panel's final recommendation summarizes the relative priorities that should be given to the various chemical agents and munitions for disposal at each storage depot. These priorities take account of the type of stored materials, the location, proximate population, and other information relevant to each site where toxic chemical munitions are stored.

RECOMMENDATION 24:

> Considering the local geography, the nature and storage conditions of the stockpile, and practices and procedures in use, the disposal priority should follow the perceived risks as designated in Table 7.

TABLE 7 Relative Priority for Disposal by Agent, Munition Type, and Location

	GB		VX		H/HD/HT		BZ	
ROCKETS	ANAD	VH	ANAD	VH				
	LBDA	VH	LBDA	VH				
	UMDA	VH	UMDA	VH				
	TEAD	VH	TEAD	VH				
	PBA	VH	PBA	VH				
BULK	APG	H	APG	H	APG	H	PBA	L
	ANAD	M	ANAD	M	ANAD	M		
	TEAD	M	NAAP	M	PBA	M		
	UMDA	M	TEAD	M	TEAD	M		
			UMDA	M	UMDA	M		
SPRAY TANKS			UMDA	M				
			TEAD	M				
MINES	ANAD	M	ANAD	M				
	UMDA	M	UMDA	M				
			TEAD	M				
			PBA	M				
BOMBS	UMDA	M					PBA	L
	TEAD	L						
ARTILLERY	ANAD	M	ANAD	M	ANAD	M		
	LBDA	M	LBDA	M	UMDA	M		
	UMDA	M	UMDA	M	LBDA	M		
	TEAD	L	TEAD	L	PUDA	L		
					TEAD	L		

The symbols designate a disposal priority as derived from a combination of probability of occurrence of an accident or incident and the seriousness of the consequences of such an event, particularly with relevance to off-site populations. Although in most cases the probability of an accident or incident is low, those cases labeled VH or H may endanger sizeable civilian populations.

VH = Very High Relative Disposal Priority
H = High Relative Disposal Priority
M = Medium Relative Disposal Priority
L = Low Relative Disposal Priority

NOTE:

ANAD = Anniston
APG = Aberdeen
LBDA = Lexington-Blue-Grass
NAAP = Newport
PBA = Pine Bluff
PUDA = Pueblo
TEAD = Tooele
UMDA = Umatilla

Part III
Report of the Technology Assessment Panel

10

Major Alternatives

From 1982 through 1984, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) allocated more than $27 million for investigations of possible techniques for disposing of chemical munitions and agents. The Technology Assessment Panel received detailed briefings by Army personnel and contractors as well as other organizations and individuals on the many features of current technology and alternative processes. Detailed descriptions and analyses of all these options, together with their possible permutations and combinations, would be outside the purpose of this report.

The major, qualitatively distinct alternatives are: placement in the deep ocean, thermal processes, chemical transformation, destruction by nuclear explosion, and some other "novel techniques." Each is discussed briefly below. The major approach favored by this panel--incineration--is treated in Chapters 11-14.

PLACEMENT IN THE DEEP OCEAN

Before 1972, placement in the deep ocean was the method of choice for large-scale disposal (see Chapter 2). Because of increasing concern over its possible environmental impact, however, this method has been prohibited by the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532). That act states, "No person shall transport from the United States any radiological, chemical, or biological warfare agent...for the purpose of dumping into ocean waters." Further, "No officer, employee, agent, department, agency, or instrumentality of the United States shall transport from any location outside the United States any radiological, chemical, or biological warfare agent...for the purpose of dumping it into ocean waters."

A principal advantage of ocean placement is that the chemical agent need not be removed from its container. The containers do not even need to be unpacked. This advantage, however, must be weighed against the known disadvantages of (a) transporting (in most cases) large quantities of explosive and highly toxic materials over great distances, and (b) the unknown effects that these munitions and agents might have on the marine environment. These unknowns include questions about whether fuzes might ignite upon striking the ocean bottom, the rate of degradation of the containers and consequent rate of release of agents, the condition of agents after they are exposed to sea water, and their effects on marine life.

Disposal of chemical agents in the deep ocean is not consistent with current national and international law, and attempting either to modify the laws or to seek an exception does not seem justified at this time. Nevertheless, ocean disposal might be suitable for some by-products of other disposal processes (e.g., metal parts that have been chemically decontaminated or salts that have been removed from scrubbers in the exhaust gas stream of an incineration facility). Such disposal would be subject to environmental regulations.

THERMAL PROCESSES

Thermal destruction processes, including pyrolysis and combustion, can be used to destroy toxic organic compounds where the toxicity is associated with the molecular structure of the compound rather than with a specific toxic element (such as lead) contained in the molecule.

In pyrolysis, the toxic material is heated to a sufficiently elevated temperature in the absence of oxygen so that the molecule decomposes to a more stable and presumably less toxic form. Combustion is generally more effective than pyrolysis in detoxifying organic materials since the products of complete combustion are either harmless (e.g., water and carbon dioxide) or can be absorbed by effluent gas scrubbers (e.g., acidic components).

Information available from both laboratory and pilot-scale studies (Brooks and Parker, 1979; Yurow, 1981) indicates that the chemical agents mustard, GB, and VX are readily destroyed by incineration (combustion). Their chemical structures do not suggest any unusual tendencies to form stable, toxic intermediate products that would not undergo complete combustion. As noted in Table 3, the Army has incinerated mustard at the Rocky Mountain Arsenal near Denver, Colorado. GB has also been incinerated at the Chemical Agent Munition Disposal System (CAMDS) at Tooele, Utah. The feasibility of incinerating VX at CAMDS was demonstrated in June 1984 (Baronian, 1984).

Thus, combustion based on an evolutionary rather than a revolutionary incineration technology is the preferred method for safe disposal of the chemical munition and agent stockpile.

In addition, the Department of Defense (DOD) generates a substantial quantity of industrial and hazardous wastes, which must be disposed of in an environmentally acceptable manner. It might be possible to increase substantially the life-cycle benefits of the disposal facilities for chemical weapons if the incineration systems could be subsequently modified to dispose of other DOD wastes.

CHEMICAL PROCESSES

An intuitively attractive approach to destroying chemical agents is to mix them with other, inexpensive chemicals and produce harmless (perhaps even useful) end products. As noted in Chapter 2, when CAMDS began operation in 1979, it tested a process of caustic neutralization to destroy GB. These tests, however, were not encouraging. Based upon laboratory measurements of chemical reaction rates, GB has a half-life of less than 1 second in a 5 percent aqueous solution of sodium hydroxide (Yurow and Davis, 1982). Thus, caustic neutralization was expected to progress rapidly. In practice, however, it was difficult to achieve the necessary mixing of components. To speed up the process, excess quantities of sodium hydroxide were added. Still, more than two weeks were often required before the GB was adequately neutralized; i.e., could no longer be detected (Scott, 1984a; Paulick, 1984).

Not only did the use of excess caustic increase the operating costs, but it also produced larger quantities of waste than had been anticipated. Calculations, based on simple chemistry, indicated that for every pound of GB destroyed about 1.5 pounds of salt wastes would be produced (Little, 1982). In actuality, about 5 pounds of wastes were produced (Jody _et al_., 1983).

These unexpected extra wastes came from (1) additional quantities of sodium hydroxide added to the mix in an effort to speed up the neutralization process, and (2) the solutions used to wash down and decontaminate the equipment. Although the salts contained no detectable amounts of agent, they could not be disposed of in an environmentally acceptable way because they contained sodium fluoride, phosphonates, and heavy metals (Jody _et al_., 1983). Moreover, these wastes were mainly organic salts that could, during the spray-drying operation, revert to GB (Jody _et al_., 1983; Scott, 1984a; Little, 1982; Yurow and Davis, 1982). Therefore, they cannot be placed in landfills without expensive precautions. Instead, they are being stored in drums at CAMDS awaiting a solution to the problem of their disposal (Jody _et al_., 1983).

The neutralization process for VX is even more uncertain than that for GB (Jody _et al_., 1983; Scott, 1984; Yurow and Davis, 1982). It seems that: (1) VX contains a contaminant, about 10 percent, that resists hydrolysis; (2) the reaction for VX is highly exothermic and might "run away," leading to an explosion; and (3) chemical neutralization of VX has never been demonstrated at the pilot plant scale.

The prospects for chemical neutralization of mustard appear even less attractive because of its low solubility and the imperfect characterization of products of the reaction process. Further, high temperature and pressure would be needed to achieve practical reaction rates (Jody _et al_., 1983).

Were the Army to choose chemical neutralization as the principal disposal method, separate facilities would be needed for each of the agents to be neutralized or, alternatively, one agent could be processed and the facilities then modified to accommodate other agents. The first option not only entails extra capital expense, but also would reduce safety by complicating the number of different processes that would have to be developed, thereby multiplying the number of things that might go wrong. The second option also requires knowing what agent will be found when an artillery projectile is opened. As noted in Chapters 12 and 14, the records on these aging weapons are not entirely complete.

Finally, the Tooele experience indicated that a facility for chemical neutralization needs two special furnaces--one for decontaminating the metal parts and a second for deactivating the explosives (fuzes and bursters) that have been removed from artillery projectiles. Earlier experience at the Rocky Mountain Arsenal demonstrated that the metal parts furnace was satisfactory for incinerating mustard (U.S. Army, 1979). Thus, the Army found it advantageous to abandon the chemical process entirely and use the furnace already at hand not only for decontamination of metal parts but also for agent incineration (see Chapter 12 for details). The design for a planned disposal facility on Johnston Atoll substituted a $2.5 million liquid incinerator for the $29 million chemical neutralization system first tried at CAMDS (Scott, 1984a). According to Little (1981), "The total cost savings when burning agents in two JACADS [furnaces] rather than neutralizing them is $19,521,000."

Despite these problems, the Army's Technology Development Program, in its concept development phase, included one contract to explore chemical procedures such as hydrolysis, anhydrous chlorinolysis, and aqueous chlorinolysis (Jody et al., 1983). None of these chemical processes showed particular promise (MITRE Corp. 1983d). Further, each required incineration of the by-products.

The contractor also investigated the possibility of converting GB to methyl phosphonic difluoride (called difluoro or DF), a constituent of binary chemical weapons. Although it is possible to produce DF from GB, no decisions have as yet been made regarding the Army's need for this chemical. In any case, difluoro produced from GB would cost about $28 per pound (this includes the expense of the disposal of GB) (Jody et al., 1983) whereas it can be manufactured commercially for about $15 per pound (Liederitz, 1984). In spite of an extensive search, no other chemical by-products of commercial value could be identified (Jody et al., 1983).

In conclusion, when compared with disposal by incineration, chemical neutralization processes are slow, complicated, produce excessive quantities of wastes that cannot be certified to be free of agent, and would require higher capital and operating costs. The panel agrees with the Army's decision to abandon chemical neutralization processes in favor of incineration.

USING NUCLEAR EXPLOSIONS FOR DISPOSAL

The concept of using nuclear explosions to dispose of chemical weapons is deceptively simple. It proposes to place all agents, packaging, metal parts, and explosives for either munitions or bulk containers in deep underground cavities and then to destroy them by exposure to the very high temperatures created by a nuclear explosion. Whatever residues are left would pose no more hazard to the environment than those from other underground nuclear explosions. A variety of methods for creating the cavities--normal tunneling, hydraulic mining, and the use of prior nuclear explosions--have been studied (Duff, 1982).

The principal advantage of disposal by nuclear explosion lies in the fact that no disassembly of the munitions or draining of agent from bulk containers would be required. Furthermore, no disposal of metal parts or other residuals would be involved.

On the other hand, there are the political and geophysical hurdles of finding an acceptable underground site and of gaining public acceptance of an underground nuclear explosion for the purpose of destroying chemical munitions. Additionally, it would be necessary to transport the chemical munitions and agents to the disposal site and place them into the underground cavity. Those operations would be costly, and would add to the risk and the political difficulties of disposal (Duff, 1982). Finally, it is not clear that this disposal method could satisfy criteria for verifiability if a treaty banning chemical munitions is agreed upon.

Thus, the problems inherent in disposal by nuclear explosions and in the transport of chemical agents seem serious enough to preclude further consideration of such disposal. Nevertheless, this disposal method might be attractive to other countries if they did not, in practice, face all of these problems.

OTHER NOVEL CONCEPTS

As part of its search for alternative industrial or experimental technologies for disposing of chemical agents and munitions, the Army made a concerted attempt to identify novel technologies that had not been previously evaluated. Numerous thermal and chemical alternatives were investigated as well as long-term storage options, the use of natural geophysical forces, and various biological, radiological, and mechanical methods.

As a result of these efforts, four approaches were identified for more detailed study (Moynihan et al., 1983):

- In-shell combustion. After removing the burster charge from an artillery shell, an oxyacetylene flame would be directed into the burster well to burn through the well and incinerate the agent in situ.
- Steam pyrolysis. After removing the burster charge, the burster well would be perforated mechanically. Then, superheated steam at about 760°C would be used either to

vaporize the agent or to blow it out of the shell. Both the agent and the shell would be heated to more than 540°C for sufficient time to render it safe.

- Drain-in-furnace. After removing the burster charge, the burster well would be perforated mechanically. The shells would then be placed in a furnace and inverted, allowing the agent to drain into the furnace for incineration. The high temperatures generated by the burning agent would decontaminate the shell from which it came.
- Underground combustion or caustic hydrolysis. Munitions would be lowered into large (e.g., 12 feet by 12 feet) chambers excavated deep underground and deactivated either by incineration or by caustic hydrolysis.

In the first three, the processing and furnace equipment could be mounted in trailers and moved from depot to depot. Whether this could be practically, reliably, and safely done has not been determined (MITRE Corp., 1983b). Any geographical consolidation of existing stockpiles would lessen the advantages of a transportable disposal system.

After reviewing these alternatives, the Army decided to consider only the in-shell combustion approach for further study. This method might significantly reduce costs with only a moderate degree of technological risk. In-shell combustion also offers a potential for high production rates (4.5 times the baseline rates discussed in Chapter 13) and does not require heavy firebrick furnaces.

Each munition type, however, would require its own specially designed system for removing lifting lugs and bursters. In addition, oxygen flow rates must be carefully controlled to prevent positive pressures and the possible buildup of explosive gas mixtures. While this system has not been proposed for handling bulk containers, it might be suited to that task (see Chapter 12). Despite its problems, the method has merit and should be explored further. It might be particularly suited for the Pueblo depot, where there are neither bulk containers nor rockets.

The panel identified one novel method of high temperature pyrolysis that has not been reviewed by the Army (J. M. Huber Corp., undated). With this method, a vertically oriented porous cylinder of refractory material is radiantly heated to about 2,500°C. Liquid droplets or fine powders are fed into the top of the cylinder, fall through it, and are destroyed. Nitrogen gas is diffused through the cylinder to prevent the feed-stock from contacting the vessel's walls. This technology might be appropriate for disposing of liquid agent drained from bulk containers or munitions. A system of this type, if it could be produced commercially, would probably be transportable.

11

Principal Elements of the Disposal Process

The thermal disposal process encompasses a number of separate elements. The actual number varies because some proposed systems combine several elements in a single operation. At one extreme, for example, one might deposit quantities of munitions still in their original packings into deep cavities, provide a large energy source (such as a nuclear explosion) and incinerate the entire mass at once. At the other extreme, the munitions might be individually disassembled and the pieces separately destroyed in, roughly, a reversal of the original manufacturing process (see Figure 8).

This chapter gives a brief overview of the principal elements of the disposal process. The following chapters describe actual processes in more detail, while Chapter 14 discusses some options for improved technology.

TRANSPORTATION

The chemical munitions and agents to be destroyed must be transported from the storage site to a disposal facility at the same depot or farther if disposal is to be carried out at a different depot. Because of the highly diverse storage conditions, this operation is likely to use conventional, labor-intensive methods and equipment. Although there has been little examination of on-site transportation in the various attempts to find better technology, it is not expected to be the rate-limiting feature of future processes.

The munitions and/or chemical agent containers need to be unloaded into a receiving area at the disposal facility. Loading, transporting, and unloading, even within the confines of a given depot, may be complicated by leaking munitions or containers that need to be overpacked in some way for safe movement.

UNPACKING

Most disposal operations now under consideration (and all proven operations) require that the munitions be removed from their packing

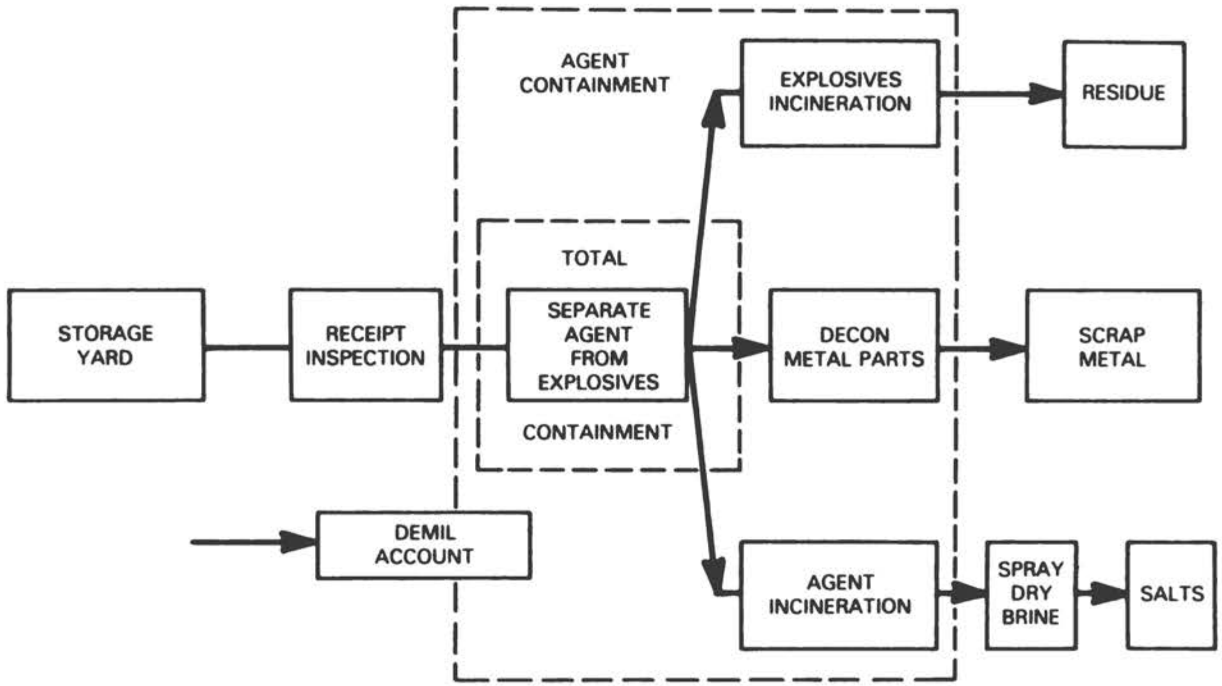

FIGURE 8 Schematic of present practice.
Source: USATHAMA.

containers and subsequently handled as individual items. Bulk containers are not generally packed. Leakers, whether munitions or bulk containers, have to be enclosed in some sort of overpacking.

Unpacking is currently done manually. If a check confirms that there are no leakers, the operators wear gloves and carry masks on their belts. If leakers are to be handled, the operators wear fully enclosed and externally ventilated special suits called "demilitarization protective ensembles" (USATHAMA, 1979).

Plans for future facilities contemplate a variety of unpacking operations that would be remotely controlled because of hazards associated with leakers. Such processes will be complicated by variable conditions, such as nonstandard pallets and highly variable methods for overpacking leakers. Dunnage from the various packing arrangements constitutes a considerable bulk of debris, and dunnage from leakers is toxic. As noted above, some concepts would avoid such complications by handling entire groups of munitions without unpacking.

GAINING ACCESS TO AGENT AND EXPLOSIVES

One must gain access to the chemical agent before it can be destroyed. Because most chemical weapons contain explosives, gaining access to the agent is a hazardous operation. It is also one of the major items of expense. For bulk containers, such as 1-ton containers or aerial spray tanks, access is relatively straightforward via existing drainage ports or by simply piercing the container. For artillery projectiles, gaining access to the agent is more difficult because of the thickness and strength of the projectile walls.

For munitions containing explosives, all present and most contemplated disposal procedures require that the agent and explosive be separated before incineration, or at least that the explosive be well exposed so that it can be destroyed without detonation. If, in addition, the munition contains a fuze, then the fuze needs to be separated from the explosive (or at least from most of it) to avoid detonation during disposal.

Much of the recent research has focused on efforts to find better ways of gaining access to the chemical agents. Whereas today's conventional or baseline technology consists essentially of mechanical disassembly, proposed approaches seek simpler techniques, ones that do not strongly depend on specific munition details. Munition-specific disassembly techniques, in addition to being relatively complex, can be frustrated by unexpected variations in assembly details or by munition deterioration in storage. Some of the proposed methods further seek to avoid handling of individual munitions (see Chapter 14).

DESTROYING THE AGENT

As discussed in Chapter 10, incineration is the favored destruction method. The chemical agents (mustard, GB, VX, and BZ) all burn readily, with destruction of the agent if combustion is complete (Barrett, 1977; Brooks and Parker, 1979; Reeves and Kartz, 1954; Pugh, et al., 1970; Wynne, 1973; Yurow, 1981).

The stoichiometric equations for the combustion of mustard, GB, and VX* with oxygen are given by equations 1 to 3 respectively (Yurow, 1981):

$$2\ (ClC_2H_4)_2S + 13\ O_2 \longrightarrow 8\ CO_2 + 2\ SO_2 + 4\ HCl + 6\ H_2O \qquad (1)$$

$$2\ CH_3-\overset{\overset{O}{\|}}{\underset{\underset{OC_3H_7}{|}}{P}}-F + 13\ O_2 \longrightarrow 8\ CO_2 + 9\ H_2O + P_2O_5 + 2\ HF \qquad (2)$$

$$2\ CH_3-\overset{\overset{O}{\|}}{\underset{\underset{OC_2H_5}{|}}{P}}-S-C_2H_4N(C_3H_7)_2 + 39.5\ O_2 \longrightarrow 2NO_2 + P_2O_5 + 2\ SO_2 + 22\ CO_2 + 26\ H_2O \qquad (3)$$

All three of these agents are reasonable fuels and have relatively high adiabatic flame temperatures (about 1,370°C) (Mink _et al_., 1983). However, since these agents contain elemental chlorine, fluorine, phosphorous, and sulfur, their combustion products, even if they contain no agent whatsoever, must be controlled. Either air pollution control systems must be used to prevent their release to the atmosphere, or the incineration process must be designed to capture them.

The detailed nature of the incineration process and associated equipment depends on the preceding "front-end" preparation work and the resultant state of the agent and munition (or container) components. For example, the agent might be (1) drained from its container and fed as a liquid to the incinerator, (2) volatilized from its container, (3) burned within the container, or (4) fed in a mixed stream into a furnace together with the container and explosive segments. In the latter, mixed-feed form, the heating value of the explosive could be used directly to help incinerate the agent.

---

*Detailed information relating to the combustion of BZ can be found in Ballantyne _et al_. (1981) and Mezey _et al_. (1980).

The existing kinetic data on agent combustion appears to be adequate for the effective design of conventional incineration systems. Additional kinetic studies may be required if designers want to substantially modify the combustion process to improve new incinerator designs. Such efforts do not seem justified in view of the finite quantities of agent involved.

DEACTIVATING THE EXPLOSIVES

Safe destruction of explosives by combustion requires that they be unconfined so that relatively slow burning (deflagration) will not transform to detonation. Detonation is extremely violent and is likely to damage surrounding equipment and/or containment vessels. Since fuzes are designed to cause detonation, they should be detached from the explosives prior to incineration. Since explosives might be contaminated with agent through leakage or through the preparation process itself, effluent from their burning must be safely detoxified before discharge to the environment.

In current practice, explosive charges (i.e., bursters) are separated from the munition by disassembly. The bursters are prepared for safe burning by shearing into several pieces (at least three) before being placed in a rotary kiln. Cryogenic fracturing techniques (see Chapter 14) might avoid the difficulties of disassembling the munitions and shearing the bursters.

DECONTAMINATING THE SOLIDS

All metal components must be adequately decontaminated prior to disposal. According to Army regulations, heating such components to a temperature in excess of 538°C (1,000°F) for 15 minutes achieves a "5X" decontamination state and renders them safe for salvage and sale (DARCOM, 1982). Such solid material has been sold as ordinary scrap metal in previous operations (USATHAMA, 1983). Metal components that have been chemically decontaminated to a "3X" state, such that no agent can be detected on the surface of the metal, may be shipped in military vehicles or in commercial vehicles with military escort.

When the Chemical Agent Munitions Disposal System (CAMDS) first began operating, a chemical neutralization process was used to destroy the agent. The solid materials were decontaminated in special furnaces (typically fired by fuel oil or electrically heated). Newer efforts are exploring concepts for simultaneous decontamination of metal components directly within the incinerator (typically, a rotary kiln) used to destroy the chemical agent.

While such decontamination is conceptually straightforward, "5X" decontamination of 1-ton containers is currently difficult and costly because of their size. An alternative for depots having only small supplies of a particular munition or bulk material might consist of draining the agent and chemically decontaminating its residue within the container to a "3X" level. The containers might then be transported to another facility for thermal decontamination. Alternatively, if the costs of transporting and processing the containers exceeds their scrap value, they might be crushed and placed in the deep ocean.

DISPOSING OF WASTES

Liquid, gaseous, and solid effluents from a disposal facility must not only have extremely low concentrations of toxic agents (see Chapter 8), but they must also meet local, state, and federal emission standards for other pollutants (see Appendix E). The known thermal destruction processes produce considerable solid waste material in the form of inorganic salts. These salts might be classified as hazardous materials under the Resource Conservation and Recovery Act because of their relatively high content of heavy metals (e.g., cadmium and lead), which come from the munitions. These materials must, in turn, be stored safely for long periods.

Packing materials also contribute a considerable stream of solid waste. If not contaminated by agent, such materials can be discarded in a landfill or destroyed in conventional incinerators. Contaminated dunnage must be incinerated or otherwise disposed of by any means consistent with the safe destruction of any agents present.

MATERIALS HANDLING

The elements of the thermal destruction system are tied together in an overall process that requires many and varied techniques for handling materials. An inherently unsteady flow of discrete munitions (or pallets of munitions) and containers is fed into the system. However, the various incinerators operate most effectively if they receive a steady flow of material.

Process design is further complicated by the hazards of handling toxic agents and explosives, and by the difficulties of ordinary maintenance tasks in toxic surroundings. Under these conditions, a simple and reliable design is unusually important. There are significant opportunities for improving and simplifying the design of systems for handling materials (see Chapter 14).

VERIFICATION

An international treaty barring the use of chemical weapons will necessarily include the destruction of the entire stockpile of agent and munitions. Doubtless such a treaty will also require strict verification of the destruction. Therefore, it is desirable to include "adequacy of verification" as one of the criteria to be used in evaluating various disposal options.

In November 1983, representatives of several foreign governments visited CAMDS to review its processes for chemical weapons disposal and their verification. The verification procedure that was demonstrated included sampling and analysis techniques (such as gas chromatography) to determine the identity and purity of the agents, and weighing individual munitions prior to and after destruction of their contents to determine the quantity of material destroyed (Mikulak, 1984). The demonstration was attended by 43 representatives of 28 countries, but not by representatives of the Soviet Union (Whelan, 1983a).

MONITORING AGENT CONCENTRATIONS

To monitor the effectiveness of the destruction process and to ensure the safety of workers, the Army needs effective, reliable, sensitive, and fast-acting instruments and techniques for sampling and analyzing of agents in all operational areas, including both the incinerator stack effluent and the ambient air. Generally, the stack effluent is saturated with water and contains a quantity of water/acid aerosols that absorb a fraction of any agent present. Hence, aerosols in stack gases must also be collected and analyzed for agent. The ambient air is largely free of aerosols, but it can contain other pollutants that interfere with agent quantification.

A monitoring system (i.e., a combined sampler, analyzer, and alarm, with recorder) should be able to detect agents rapidly in either the stack or the ambient environment. It should discriminate between the agent and other background chemicals to minimize false alarms. The monitoring system should also be reliable, maintainable, and highly automated. A monitoring system currently under development by the Army may meet these requirements.

Mass spectrometry may have the greatest potential. Two promising developments are the Navy's central atmospheric monitoring system (CAMS II) and the atomopheric pressure ionization radio frequency mass spectrometer (APIMS-I), currently under development (NRC, 1984).

Sampling and analysis problems are particularly severe for VX because of its low vapor pressure, its thermal instability, and its propensity to be adsorbed on almost any surface, including feed lines between the point to be measured and the measuring instrument. Thus, instruments for detecting VX must be extremely sensitive.

12

Current Facilities and Techniques

DRILL AND TRANSFER SYSTEM

The Drill and Transfer System (DATS) is a portable facility, mounted on a series of trailers, designed to drain chemical agents from leaking munitions at the depots where they are currently stored. As the name implies, the agent is reached by drilling through the munition wall. The agent is not destroyed. Rather, it is transferred to a suitable container for safe storage. After being drained, the munition casings are decontaminated chemically. Explosives are left within the casings to be destroyed later by detonation.

DATS can process about one munition per hour. This is done individually and manually within a glove box. Drilling is accomplished with an ordinary twist drill in a drilling machine equipped with safety interlocks to avoid excessive penetration that might detonate the explosive elements within the munition.

The DATS system began pilot testing at Dugway Proving Ground in Utah in 1980. It is currently making the rounds of depots, processing accumulated stocks of leakers. DATS is scheduled to complete its round of visits in 1985 and then to stay at Dugway Proving Ground, having processed about 800 munitions.

DATS or other facilities of similar design might continue to process newly discovered leakers or occasional troublesome munitions that, for whatever reason, cannot be handled by the large production facilities now being developed. DATS might be used to remove the agent from duds discovered on firing ranges where chemical munitions have been fired in the past, but the risk of handling potentially armed and fuzed munitions in a glove box seems excessive.

CHEMICAL AGENT MUNITIONS DISPOSAL SYSTEM

The Chemical Agent Munitions Disposal System (CAMDS), located at Tooele, Utah, is designed as a flexible facility for developing and testing disposal technology. It has already been used to dispose of considerable quantities of unserviceable munitions at Tooele (see Chapter 2). Technology developed at CAMDS is to be used for the disposal of rockets and land mines at various locations, and for designated stocks at Johnston Atoll. The Johnston Atoll Chemical Agent Disposal System (JACADS) is a direct descendant of CAMDS, in many respects using similar equipment.

CAMDS can dispose of all types of munitions and containers in the chemical stockpile. To do so, it uses a variety of equipment serviced by numerous and sometimes complex conveying systems. CAMDS was first used for chemical neutralization of GB, but that process proved too slow and difficult (see Chapter 10). Subsequently, incineration of both GB and VX was found effective. Mustard can also be incinerated, as was proven at the Rocky Mountain Arsenal. BZ was incinerated in tests conducted at Pine Bluff and at an independent laboratory (Ballantyne et al., 1981; Mezey et al., 1980).

Several types of furnaces and burners are available for thermal processing of materials, including a rotary kiln deactivation furnace and a three-stage, roller hearth furnace for decontaminating metal parts. There are also dunnage and liquid incinerators. All are equipped with appropriate afterburners and/or pollution control systems. Table 8 summarizes the destruction techniques currently in use.

A 30-foot-long rotary kiln is used to burn explosives and propellant elements from rockets, landmines, and projectiles, at the same time that it decontaminates their associated metal components. Explosives and propellants are chopped into small pieces to expose sufficient surface area to avoid triggering detonation during burning.

The furnace is gravity-fed through a double-tipping valve. It discharges onto an electrically heated discharge conveyor. The latter provides sufficient temperature for the time required to ensure complete "5X" decontamination of metal parts. Gases discharged from the furnace are passed through an afterburner (to ensure complete destruction of agent traces) and emission control systems prior to being exhausted to the atmosphere.

The stack effluents from the Chemical Agent Munitions Disposal Systems comply with relevant emission standards for both GB and VX (USATHAMA, 1983b; Baronian, 1984). The maximum emission limits, which were established by the surgeon general of the Army, (expressed in milligrams per cubic meter) are: GB - 3×10^{-4} averaged over 2 hours; VX - 3×10^{-5} averaged over 2 hours; and mustard - 3×10^{-2} averaged over 1 hour (USATHAMA, 1983a). These emission requirements have been published in environmental impact statements and reviewed by the Environmental Protection Agency (EPA).

While detailed statements of approval were not evident to the panel, EPA's review of the final enviromental impact statement for the Drill and Transfer System at Dugway Proving Ground, which operates under the same agent emission limits, listed "no serious objection to the proposed procedure..." (Hasson and Kilmer, 1978). Similarly, a letter dated July 14, 1971 from J. Steinfeld, surgeon general of the Public Health Service, to Vincent P. Huggard, acting assistant secretary of

TABLE 8 Baseline Technology for Disposal of Chemical Munitions: Destruction

MUNITION TYPE	DESTRUCTION OF ENERGETIC MATERIALS	DESTRUCTION OF AGENT	DECONTAMINATION OF METAL PARTS
M55 Rockets with GB & VX	DEAC Furnace	Liquid Incinerator	Heated Discharge Conveyor
M23 Land Mines with VX	DEAC Furnace	Liquid Incinerator	Heated Discharge Conveyor
Projectiles with GB & VX	DEAC Furnace	Liquid Incinerator	Metal Parts Furnace
Projectiles with H	DEAC Furnace	Metal Parts Furnace	Metal Parts Furnace
Bombs with GB	---	Liquid Incinerator	Metal Parts Furnace
Mortars with H	DEAC Furnace	Liquid Incinerator	Metal Parts Furnace
TCs with GB & VX	---	Metal Parts Furnace	Metal Parts Furnace
TCs with H	---	Metal Parts Furnace	Metal Parts Furnace

DEAC = deactivation furnace that decontaminates the metal
TC = ton container
Source: Scott, 1984b.

the Army for installation and logistics, offered the following recommendation: "The maximum emission into the atmosphere of agent GB from any source shall be less than 0.003 mg/cum." This is exactly the same as that set by the Army surgeon general.

The CAMDS decontamination furnace for metal parts (and a similar one for JACADS) is a large unit costing more than $9 million--it is the most expensive item in the entire array of equipment (Scott, 1984b). It is used both to process agent-filled items and to provide "5X" decontamination of metal components. It is designed to volatilize chemical agents from containers or projectiles. In spite of its relative slowness, this process was selected in view of prior difficulties encountered in draining some mustards from containers (Jody et al., 1983; Lawhorne, 1977; USATHAMA, 1983a). As discussed in Chapter 14, this volatilization process seems unnecessary. Programs are already under way to develop improved technologies that drain the agent and destroy it in liquid incinerators.

The metal-parts-decontamination furnace has three chambers. The first is an unheated station wherein 1-ton containers are pierced. The second volatilizes the agent, while the third heats the metal container to provide "5X" decontamination. The furnace is fired by fuel oil and can process a single 1-ton container in about two hours. The furnace is also used to process groups of projectiles in eggcrate-like carriers of cast stainless steel.

Effluents from the volatilization chamber are destroyed in a primary burner and then passed into an afterburner, where they are joined by effluent from the decontamination chamber. They then pass through a pollution control system where acids (e.g., hydrochloric and hydrofluoric), particulates, and other undesirable materials are scrubbed out and prepared for storage and subsequent disposal. Gases emitted to the atmosphere are carefully monitored to ensure that they are within the allowable limits established by regulation.

Clean dunnage is burned in a conventional incinerator while contaminated dunnage (from leakers) is burned either in the deactivation furnace or in the metal parts furnace.

As summarized in Table 9, preparation of munitions for incineration is entirely a mechanical process. Munitions containing explosives have been processed in a large (10 feet in diameter by 24 1/2 feet long) explosive containment cubicle (cylinder) having 2 1/2 inch-thick steel walls, designed to safely contain an accidental detonation of an 8-inch projectile. A larger explosive containment room with reinforced concrete walls has been designed for the same purpose at JACADS. It will first be tested at CAMDS as a replacement for the existing explosive containment cubicle.

Thin-skinned munitions, including the M55 rocket with its aluminum shell and the M23 land mine, can be "opened" by mechanical shearing. The rocket is sheared into five pieces (see Chapter 14) while still in its fiberglass shipping container/launch tube. Segmenting was first done by sawing rather than shearing, but frequent difficulties were encountered. In fact, the saw caused two propellant fires within the explosive containment cubical (Paulick, 1983). Nevertheless, thousands of rockets have been destroyed this way.

TABLE 9 Baseline Technology for Disposal of Chemical Munitions--Front-end Measures

TYPE OF MUNITIONS AND METHOD OF SIZE REDUCTION	ACCESS OF AGENT	REMOVAL OF AGENT	REMOVAL OF EXPLOSIVES
M55 Rocket Shear	Punch	Drain	Remain in Rocket
M23 Land Mine Punch Out Booster	Punch	Drain	Remain in Mine
Projectiles with GB and VX Shear	Burster Well Removal	Drain	Reverse Assembly
Projectiles with H Shear	Burster Well Removal	Volatiliza-tion	Reverse Assembly
Bombs Not Applicable	Punch	Drain	No Explosives
Mortars No Reduction	Burster Well Removal	Volatiliza-tion	Reverse Assembly
TCs with GB & VX No Reduction	Punch	Drain	No Explosives
TCs with H No Reduction	Punch	Volatiliza-tion	No Explosives

TC = Ton Container
Source: Scott, 1984b.

More recently, a far simpler, guillotine-like shearing device has been used to make thousands of cuts without igniting the propellant or bursters and with negligible blade wear (Seat, 1984b). A similar, though smaller, shear has also sliced through many bursters (in their tubes) without difficulty.

Heavy-walled munitions, such as artillery projectiles, are opened by disassembly. The nose closure, either fuze or lifting ring, is unscrewed and various underlying pieces (sometimes variable arrays of such pieces) are extracted mechanically. The burster, if present, is extracted with a vacuum system. Access to the agent is then achieved by removing the pressed-in burster well (see Figure 3). The burster well is simply gripped by an expanding internal collet and pulled out.

This operation is sometimes frustrated by a welded-in burster well,* in which case the weld must be machined away and extraction attempted again. The agent might be pumped from the open projectile or volatilized from it in the metal parts furnace. Pumping through a vertical suction tube is preferred to simply inverting the munition because the pump can be monitored to indicate progress.

The work stations used to perform these disassembly tasks are arranged in a linear fashion along one or more conveyor lines. This arrangement is easily modified to try different components and to accommodate different munitions. A carousel-type machine, typical of multistage machining operations, though less flexible, would be more appropriate for production operations. Carousel designs have been specified for JACADS and prototype machines are first to be proven at CAMDS.

At first glance, CAMDS is far more complex than necessary, but this complexity is in keeping with the flexibility demanded of a research facility that experiences the typically random growth of new operations. The facility has provided necessary design information for JACADS (indeed, much equipment will be duplicated) and for the expedited M55/M23 disposal program. It will continue to provide necessary design data (for example, how much torque can safely be applied to extract a fuze?) and prototype operating experience. CAMDS may provide sufficient capacity for a gradual disposal of some munitions, but it is not suitable for disposal of the entire Tooele stockpile.

INDUSTRIAL TECHNIQUES AND RESEARCH

In its search for available technology or promising approaches for destroying chemical munitions, the panel's staff contacted the Environmental Protection Agency, the Hazardous Waste Treatment Council, the Hazardous Material Control Research Institute, the American

---

*An assembly technique of highly questionable safety, apparently not recorded at the time of manufacture or in munition records.

Chemical Society, and the Chemical Manufacturers Association. These contacts were followed by interviews with corporate representatives and individuals working in the field. From these and other discussions, it became apparent that in dealing with hazardous wastes industry first attempts to find a way of using those wastes as a resource. If that is not possible, corporations will search for some means of chemical neutralization. Where those options are unavailable, they will either burn the material or, in some cases, consider deep burial.

In general, industrial experts favored thermal destruction for chemical agents. Possible methods included the use of rotary-kiln furnaces, fluidized-bed incinerators, high-temperature pyrolysis, microwave heating, and decomposition by exposure to superheated water. Most of these thermal technologies are already being used for hazardous waste disposal. A few, however, are still in the experimental phase. Of these methods, high-temperature pyrolysis was the only one that had not already been considered by USATHAMA. It might have some potential for use in a mobile system for destroying liquid agents stored in bulk containers (see Chapter 14).

13

Planned Disposal Programs

The Army's current plans include the disposal of BZ at Pine Bluff Arsenal, an expedited M55 rocket/M23 land mine disposal program, and the disposal of obsolete and unserviceable stocks on Johnston Atoll.

BZ DISPOSAL

The Army's entire stock of the incapacitating agent BZ is located at Pine Bluff Arsenal. The inventory includes bulk agent (a white crystalline powder), an agent-pyrotechnic mix loaded into two kinds of cluster bombs, BZ-contaminated liquid residues from earlier manufacturing operations, and residue from a 1971 fire in a storage igloo (USATHAMA, 1982).

Disposal of BZ was assigned to the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) in 1976. Research completed in 1981 indicated that incineration was the best method (USATHAMA, 1982). Design studies recommended a disposal facility for BZ that would be similar in many respects to facilities needed for disposing of other chemical munitions stored at Pine Bluff.

Accordingly, the facility is to be converted to dispose of M55 rockets and M23 land mines after the BZ has been destroyed. Later, it might again be converted to dispose of mustard stored in 1-ton containers. Construction of the BZ facility is scheduled to start in 1984 with disposal operations occurring in 1987-1988.

Munitions containing BZ are to be made safe for handling by soaking them in water (the pyrotechnic mixture is an extreme fire hazard). Afterward, the various munition clusters are to be manually disassembled into individual submunitions and then detoxified in a deactivation furnace (the same type of furnace used for explosives at CAMDS). This furnace should also be suitable for rockets and land mines. Liquid residues are to be detoxified in incinerators designed for burning liquids. Metal parts are to be decontaminated by heat treatment. The processes should produce no liquid effluent, so that no gaseous emission controls for sulfur or nitrous oxides or other pollutants should be required (Balachandran and Roux, 1982; USATHAMA, 1982a).

EXPEDITED M55 ROCKET/M23 LAND MINE PROGRAM

M55 rockets are stored at five depots in the continental United States and on Johnston Atoll. Filled with VX or GB in the 1960s, these thin-skinned, aluminum munitions are deteriorating more rapidly than other munitions, resulting in increased maintenance costs (USATHAMA, 1982a). An expedited M55 disposal program was authorized and funded in March 1983 (Roux, 1984). The two kinds of munitions might be processed by similar means since both are thin-skinned vessels and in neither case can the explosive elements be removed without releasing the agent (USATHAMA, 1982b).

The expedited program is to use CAMDS technology and advances in that technology as available. Primarily, this includes the rocket shear machine (or a land mine punch), the deactivation furnace, and improved air pollution control equipment consisting of a downstream afterburner, a spray-dryer, scrubber, and baghouse. CAMDS technology is described in Chapter 12. Often used for industrial purposes, the new, dry gas scrubber system being tested, is simpler than the wet scrubbers used at CAMDS and is expected to have lower operating costs (Roux, 1984). The wet scrubber does not require a baghouse.

One obvious question is whether the M55 disposal program should be delayed pending development of a cryogenic fracturing technique (see Chapter 14) to replace the rocket shearing technique. The answer is "no." First, the shearing machine has proven to be safe, reliable, and far simpler than a cryogenic system (Seat, 1984). Second, the major safety advantage attributed to cryogenic methods (MITRE, 1983c), that of near-zero vapor pressure of the frozen agent, is illusory. Frozen fragments of agent would be scattered widely, and surrounding equipment and surfaces would soon become covered with melted agent.* Third, the aluminum alloy (6061) used in M55 rockets is not embrittled at cryogenic temperatures (General Atomic, 1982; Van Horn, 1967). Indeed, this alloy is commonly used for cryogenic equipment.

The expedited program has progressed through many planning steps and applications have been made for necessary environmental approvals (see Chapter 8 and Appendix E for a comprehensive list of applicable laws and regulations). Design specifications have been completed and a contract has been awarded to design the process equipment. A 1- to 3-year operating schedule (1989-91) is anticipated (Roux, 1984). Any disposal equipment remaining after the rockets and land mines have been destroyed would be used to dispose of other munitions and agents at each depot.

---

*Unless, of course, they are also held at cryogenic temperatures, but that would entail design complications unlikely to improve safety or reliability.

JOHNSTON ATOLL STOCKS

Quantities of all items in the U.S. chemical weapons arsenal (except BZ) are stored on Johnston Atoll. Many have begun to deteriorate. Currently, 40 percent of the Johnston Atoll stockpile is designated as obsolete and available for disposal (USATHAMA, 1982a).

An "accelerated" project has been established (USATHAMA, 1982a) to design and construct the Johnston Atoll Chemical Agent Disposal System (JACADS). This facility is to use technology developed and demonstrated by CAMDS, together with improvements that arise as planning and construction progress. While the facility will be designed to dispose of the entire Johnston Atoll stockpile, to date USATHAMA has been authorized to procure only that equipment needed for M55 rockets and M23 land mines (Whelan, 1983b).

JACADS facility design is now well along and a contract has been let for initial equipment design. The schedule calls for facility construction to start in 1985 and extend through 1987. Equipment is likewise to be procured and installed between 1985 and 1987. Training is to start in 1988 and disposal operations in 1989. If approved, additional equipment could be acquired by 1991, with disposal of the remaining stocks between 1991 and 1993 (Whelan, 1983b).

JACADS is a direct descendant of the thermal destruction technology developed at CAMDS. Improvements in materials handling (notably the use of rotary, multipurpose processing machines) should give JACADS a throughput rate about twice that of CAMDS. Gaining access to the agent and separating the explosives from the agent will be done mechanically. Recent tests (Brankowitz, 1983), which indicated that distilled mustard agents were in a liquid (i.e., drainable) state, might permit processes that do not require the relatively slow agent volatilization step previously assumed (see Chapter 14).

The thermal destruction equipment planned for JACADS is identical to that at CAMDS (see Chapter 12). The explosives deactivation system will consist of a 30-feet long by 4-feet in diameter cast steel rotary kiln, a cyclone, and a slagging afterburner.

The three-chamber, roller hearth furnace used to decontaminate metal parts from drained munitions is expected to have the following peak hourly rates: 105 mm projectiles - 181; 155 mm projectiles - 90; 8-in. projectiles - 47, 500-lb. bombs - 2.4; 750-lb. bombs - 2.5; 1-ton containers - 1.66; and 4.2-in. mortars - 180 (JACADS, undated).

Fumes and vapors from the furnace's volatilization chamber are to be destroyed in a primary burner, followed by an afterburner. A separate incinerator is to be used for destroying drained agents and decontamination solutions. A dual-chamber design should permit incinerating a maximum of 700 pounds per hour of VX, 1,050 pounds per hour of GB, 1,330 pounds per hour of mustard, and 2,000 pounds per hour of decontamination solution.

Dunnage, both clean and contaminated, is to be destroyed in a two-chamber incinerator. Solid waste is to be fed manually through a ram feeder into the first chamber. Fuel oil is to be used to start and maintain combustion.

The JACADS design includes pollution control systems to treat the effluent from all combustion chambers. Pollutants of concern include sulfur dioxide, hydrochloric acid, hydrofluoric acid, and phosphorous pentoxide. The systems include a quench tower, variable throat Venturi scrubber, packed-bed wet scrubber tower, and necessary pumps and blowers (JACADS, undated). Scrubber liquors are dried to reclaim salts in dry form for storage. Drum dryers have been used in CAMDS, but spray dryers are being considered for future facilities (Shatto, 1983).

Munitions are to be prepared by mechanical systems tested at CAMDS, but designed for higher throughput. Munitions containing explosives are to be processed in two separate containment rooms. Each of the two preparation lines should be capable of higher throughput than the deactivation furnace, so each could, on average, operate at half capacity or less. In view of the undesirability of a furnace interruption for lack of feed and the relatively low cost of a preparation line, this redundancy is justified. Overcapacity with existing preparation equipment suggests that, although simpler and more reliable equipment is always desirable, there is no need to delay the disposal of M55 rockets pending its development.

While the JACADS design provides for higher throughput than that of CAMDS, there is still considerable room for refinement and simplification. As an illustration, consider the way that JACADS handles projectiles containing explosives. The projectiles are to be unpacked manually and placed individually on a conveyor that carries them into the containment room. The projectiles are then transferred individually from the conveyor to a rotary indexing machine that removes their fuzes or nose plugs, supplementary charges, and bursters. Next, they are transferred to a second conveyor and carried out of the containment room to be individually transferred by a multiposition loader to a tray to be forwarded by a batch transfer system.

Empty trays are to be delivered by forklift truck. When loaded, each tray is to be conveyed and transferred to a charge car for transfer to the "multipurpose demilitarization machine." Projectiles are then removed from the tray by a pick-and-place robot and loaded individually into the machine. On that machine, the burster well is to be removed, agent pumped out, the burster well replaced, removed again, deformed to prevent sealing, and replaced again. The empty projectiles are then removed from the machine, transferred further, and eventually carried, in batches again, into the metal parts furnace in a heavy stainless steel tray. The complexity of this particular progression is evident. In part, it provides buffering to accommodate temporary shut-downs of the many and varied pieces of equipment.

The panel, in its brief review of this system, is certainly in no position to criticize authoritatively the specific design details. However, it does seem possible, if not likely, that excessive complexity might actually introduce more interruption than it alleviates. Therefore, every attempt should be made to simplify the system design for later disposal programs.

It might be particularly fruitful to explore systems that further exploit drainage and subsequent burning of agents in a simple liquids incinerator, and designs that more nearly approximate steady flow of all material streams (including solids). The rocket disposal schedule provides time for such rethinking, and CAMDS, as intended, provides a development site where exploration of such modifications would not prejudice a prompt disposal program for Johnston Atoll.

The rocket disposal program itself would benefit from simplification. An expedited search should be undertaken for design simplifications in that program prior to final equipment specifications. However, the program should not be delayed awaiting any particular new concept development.

BASELINE TECHNOLOGY

Establishing a Benchmark

As noted in Chapters 2 and 10, the Army is actively engaged in the exploration for and the development of advanced disposal technologies. The aim is to substantially reduce the estimated costs for disposing of the stocks that remain after all rockets, land mines, and BZ have been destroyed. An important first step, however, is to carefully assess the cost and time that would be required if current or "baseline" technology were to be used. Such an analysis has been completed (Scott, 1984b) and a benchmark has been established against which alternative technologies may now be compared.

Baseline technology is essentially that developed at Tooele for CAMDS, but the final selection of its components was delayed until preliminary design work on JACADS could provide a basis for assessing proven technology. Baseline technology available in 1984 would be used to dispose of the entire stockpile should the Army need to proceed immediately. For example, recent calculations show that baseline technology could reduce the total cost of disposal from an early estimate of $4 billion (Ambrose, 1982), to perhaps $1.5 billion (Hidalgo, 1983). Cost requirements to be met by worthwhile new technology, therefore, seem more stringent than originally perceived.

Like CAMDS and JACADS, baseline technology punches and disassembles the munitions mechanically to gain access to agent and explosives. Likewise, it uses incinerators to destroy the agent and explosives. These various methods at the "front end" of the process are summarized in Table 9; thermal destruction elements are listed in Table 8, where the deactivation furnace is a rotary kiln and the metal parts furnace is a large three-chamber hearth furnace. Other key pieces of baseline equipment include a dunnage incinerator, explosive containment chambers, various special mechanical devices to disassemble, punch, and manipulate items as necessary, and the necessary air pollution control systems.

Cost Estimates

In the most recent study (Scott, 1984b), cost estimates were based on each depot's actual stockpile. For each site, the postulated disposal facility consisted only of those elements from the baseline repertory required by the items at that particular depot. Elements were not subdivided; i.e., selection of a furnace meant selection of the baseline size as well as type. Where appropriate, the study accounted for savings made possible by conversion and use of components that would be remaining after completion of the expedited M55/M23 program. All anticipated costs were included, such as construction, support facilities, security, training, start-up, changeover between munitions, shut-down, clean-up, and so on.

The cost analysis sought to find a limited optimum arrangement at each site--limited in the sense that only integer numbers of baseline technology elements were used. The best selection (that is, minimum total disposal cost) might be expected to fall between high-speed operations having very high capital costs but low (short duration) operating labor costs, on the one hand, and lower speed operations with lower capital costs but higher operating labor costs on the other. These are shown schematically in Figure 9.

Assuming that appropriately selected base line facilities were constructed at each site, the total cost for destroying all stocks that would remain in the continental United States and on Johnston Atoll after the rocket, land mine and BZ programs had been completed came to more than $1 billion. If, instead, all remaining munitions and agents were transported either to the Tooele or Anniston depots (whichever was closer), then the disposal cost, using baseline technology, was estimated to be $690 million, plus transportation costs. Transportation costs were not estimated, but would probably be substantial. In 1979, for example, the Army spent about $6 million to move some 900 items from the Rocky Mountain Arsenal to Tooele (Shatto, 1983). The destruction of rockets and land mines is expected to cost approximately $262 million (Roux, 1984). BZ will add another $93 million (Whelan, 1984).

Thus, according to these most recent Army estimates, the total cost for destruction of all chemical weapon and agents in the continental United States and on Johnston Atoll, using today's baseline technology, is $1.4 billion, assuming no movement between depots. If, on the other hand, the rockets and BZ were destroyed at their current sites, but remaining stocks only at Tooele and Anniston as well as on Johnston Atoll, then the total cost would be slightly more than $1 billion plus transportation costs.

One rather surprising result of this analysis was that for all but one site, the best selection appeared to be at lower than available capacity; that is, the baseline technology equipment is too large for

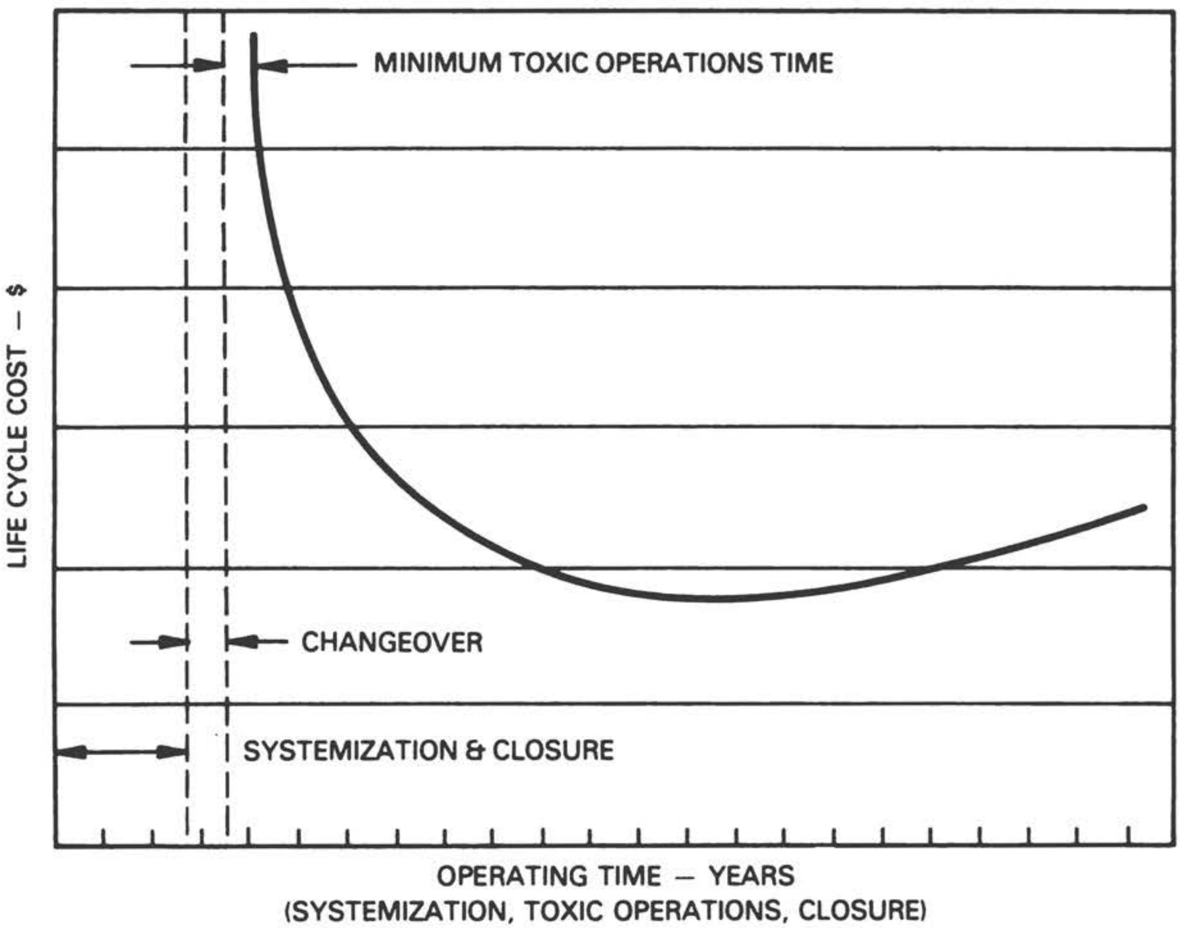

FIGURE 9 Typical disposal cost versus time.
Source: Scott 1984b.

all but one site (see the example in Figure 10).* Because of its rather large size (necessitated by the baseline technology for disposal and decontamination of 1-ton containers) and the fact that it is the costliest single piece of equipment, the large metal parts furnace appears to be a major factor in this result (Scott, 1984b).

The Army has already used these results in seeking a better match between the system to be selected and actual stockpile requirements. The panel believes that this study was done well in terms of the selection of current technology for the baseline, in terms of its thoroughness, and in terms of learning from and acting upon the findings.

One final word seems appropriate: in this and other chapters of the report, there is frequent reference to cost effectiveness as a major criterion for choice. Considering all of the potential costs of a mishap, designs that are simpler and more foolproof should be preferred even if their initial cost is higher.

---

*JACADS was excluded from this study because it essentially is baseline technology. Further, it will be operating prior to completion of the M55/M23 program.

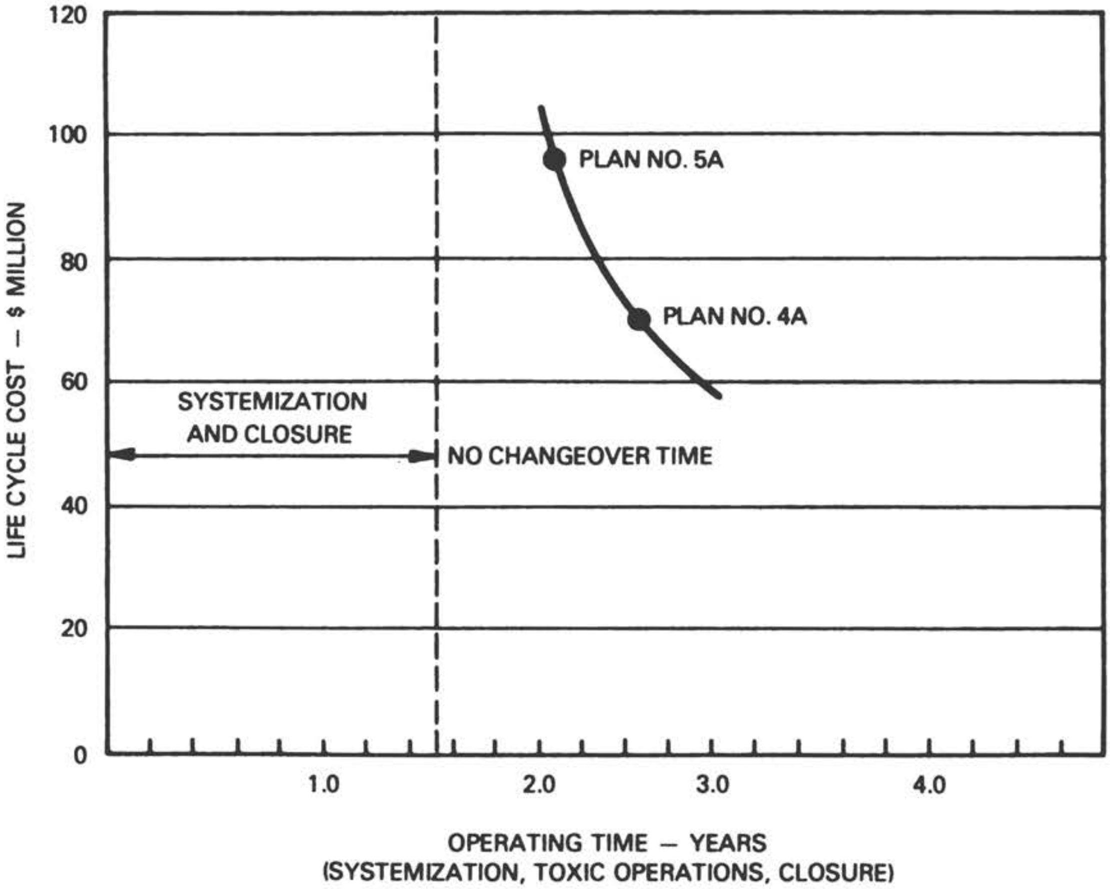

FIGURE 10 Cost versus operating time for disposal of stocks at Newport Depot.
Source: Scott 1984b.

14

Options for Improved Technology

Thermal processes hold the greatest promise for reliably and economically destroying chemical agents in munitions and bulk storage containers (see Chapter 10). The experience gained at the Chemical Agent Munitions Disposal System (CAMDS) can now be applied to production facilities such as those planned for Johnston Atoll.

Still, substantial improvements may be made in later systems. The Army has recognized this opportunity and considered a great many options for improved designs. The choices among these various options, however, will not be based solely on technical merit. Three constraints that exert a powerful influence on the selection are:

1. The overwhelming importance of safety in all operations (see Chapter 15).
2. The terminal nature of the disposal effort--the Army is preparing to destroy a finite quantity of material, not to establish a new industry.
3. The need to expedite disposal of M55 rockets and BZ.

These factors militate against substantial departures from proven technology. The first two discourage concepts that require long or costly development or that can be meaningfully tested only at full scale. The third, which will establish functional facilities at some sites, gives incineration techniques, particularly the use of rotary kilns, a substantial advantage for any subsequent disposal operations.

Despite such an inclination toward proven technology, an extensive search for substantially improved equipment is well justified. It is important to be as sure as reasonably possible that the best process, in terms of safety and cost, has been selected from all known candidates.

This chapter examines some of the more promising approaches and suggests a few simplifications. No attempt is made to catalogue and critique all of the concepts treated in detail by Army studies.

Figure 11, which was developed by the panel, illustrates some of the many possible options for thermal processing. With so many options available, this particular diagram is not unique, and one can readily identify hybrid systems that fall outside the illustrated functions. Choices among basic approaches are determined by overall constraints and/or interactions among the system components.

In general, the disposal process begins with a mixture of items, of widely various sizes and container strengths, some including explosives, with various types of packing. Despite the apparent intervening maze, there are really only two end points to the many paths in terms of basic influence on process steps: the large, essentially one-shot batch operation using massive destruction techniques (e.g., nuclear explosion) and the relatively continuous operation of more conventional destruction devices (thermal devices in this case). The former are necessarily unsteady, pulse-type operations; the latter are preferably steady flow. By anticipating the end-point, steady-flow destruction device, designers of "conventional" disposal facilities can do much to keep the entire process simple.

The variety of stored materials, along with concern for the four separate material streams (agent, explosives, metal parts, and dunnage), complicates the selection of preparation steps. Massive destruction techniques like nuclear explosions simply avoid these complications by eliminating preparation altogether. This is, in fact, the major potential advantage of these techniques.

As explained below, the preference for steady feed to an incinerator can influence the selection of many preparation steps. Local batch preparation steps (e.g., pallet-size processing illustrated in Figure 11) might appear economical, but they are not inherently so because of the importance of steady material flow.

THERMAL PROCESS OPTIONS

USATHAMA contractors (Dustin et al., 1983; Mink et al., 1983; MITRE, 1983d; Schultz, et al., 1983) have studied various thermal processes in an effort to improve system safety, process performance, reliability, and economics over that achieved by CAMDS. Other contractors (MITRE, 1983b; Moynihan et al., 1983) have also evaluated novel concepts for the disposal of obsolete chemical wastes.

It is beyond the scope of this report to provide a comprehensive review of the advantages and disadvantages of the many technologies studied. However, the following paragraphs briefly review the conventional and novel thermal alternatives that show promise for enhancing or replacing the CAMDS baseline technology. They also consider the effects that current high-priority Army programs might have on the selection of alternatives.

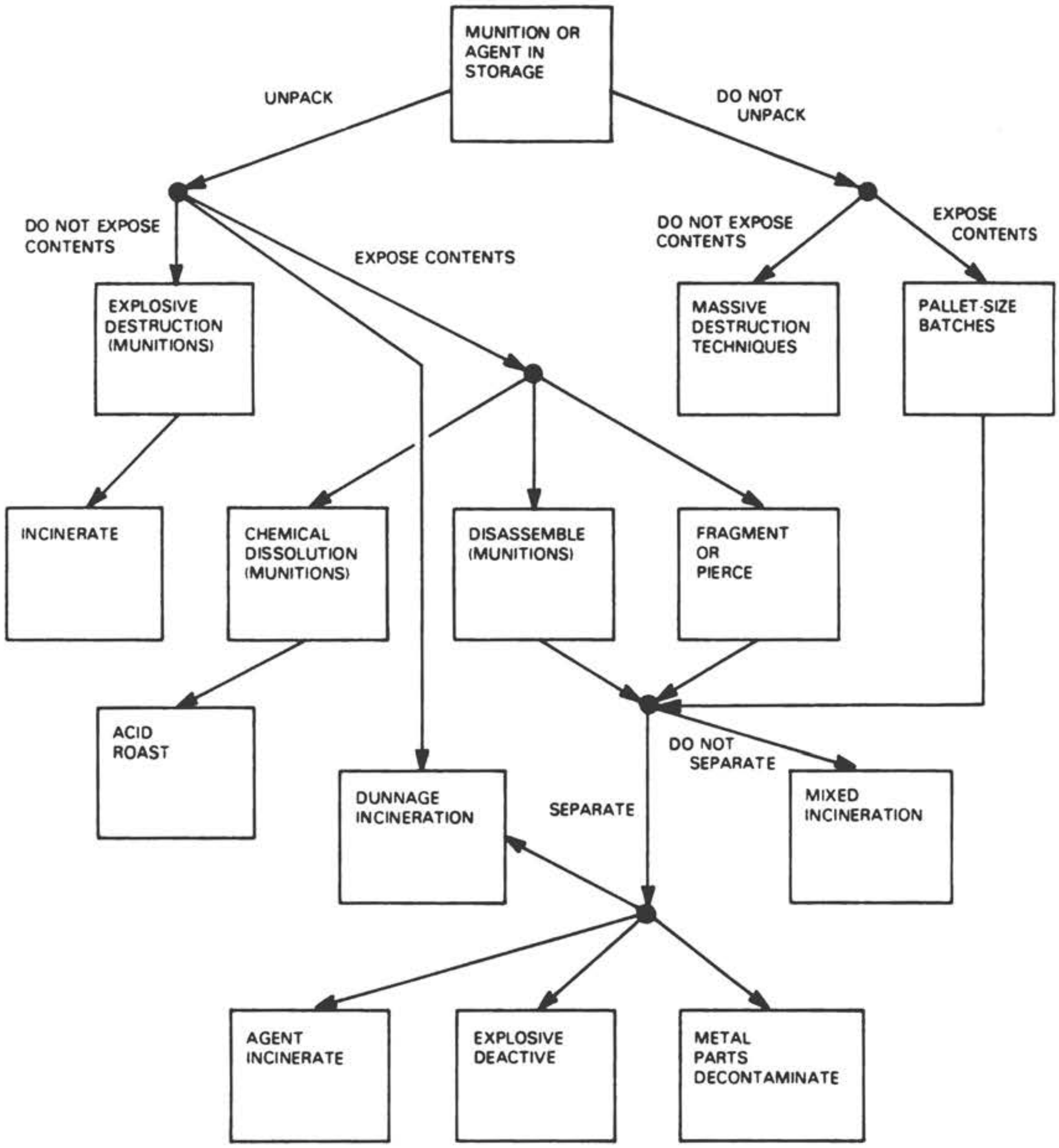

FIGURE 11 General disposal options.

More than 120 individual or hybrid thermal concepts were identified and considered by three USATHAMA contractors who evaluated alternative processes using conventional thermal means for disposing of obsolete chemical munitions. Approximately 40 novel thermal concepts were also evaluated. Table 10 summarizes some of the criteria used to evaluate these concepts.

Both the conventional thermal processes and the novel processes recommended for additional study by the contractors are summarized in Table 11.

The novel concepts included biological processes, chemical neutralization, use of natural geological forces, nuclear explosions, and long-term storage. In the end, however, all novel concepts recommended by USATHAMA contractors for future study were based on thermal processes. Appendix F provides an overview of these conventional thermal processes and the one most promising novel process. Appendix H summarizes their relative costs.

One additional thermal process has some probability of technological and/or economical success. This process uses very high temperature pyrolysis to destroy gravity-fed liquids (J. M. Huber, undated; Lee and Lewis, 1983).

Incinerator systems designed for steady-flow operation are more readily controlled than those designed for batch operations. Additionally, the incinerator, as well as the required downstream air pollution control systems, can be smaller and less costly for steady state than batch operations.

The safety and operation of an incinerator are greatly improved if (a) the fuzes are separated from the explosives and (b) the explosives and propellants are separated into relatively small and unconstrained pieces. Additionally, for best operation, the agent should be readily accessible and the metal parts should not be too large. Attention to such considerations can provide steadier flow conditions, reduce wear on the components, enable the use of smaller and less costly furnaces, and minimize the risk of explosions.

Thus, the complexity and cost of incinerator systems generally decrease as the degree of munition preprocessing increases. Therefore, incinerator design needs to consider both the pre-processing and destruction portions of the process. Technological opportunities associated with front-end preparation are discussed below.

PREPARATION OPTIONS

Figure 11 shows several preparation options among the paths culminating in a steady-flow thermal destruction. Tracing the options used in CAMDS and JACADS provides a useful example (see Figure 12). Artillery projectiles are unpacked, the contents are exposed by disassembly, the burster tubes are sliced, the material streams are

TABLE 10 Selected Criteria for Evaluating Alternative Thermal Concepts for the Disposal of the Obsolete Chemical Munition and Agent Stockpile

Safety
Life-Cycle Cost
Probability of Development Within 5 Years
Degree of Technological Risk
Scalability of the Process from Laboratory to Production Rates
Availability, Reliability, and Maintainability of the System
Ease of Operation
Energy Requirements and Sources
Material Compatibility Problems
Preprocessing Requirements
Posttreatment Requirements

Source: Shatto, 1983

TABLE 11 Conventional Thermal Disposal Processes and Novel Processes Recommended by Contractors in USATHAMA's Technology Development Program

CONVENTIONAL THERMAL PROCESS	NOVEL PROCESS
Acid Roaster	In-Shell Combustion
Thermal Tower	Steam Pyrolysis
Rotary Kiln	Drain-in-Furnace
Rotary Kiln/Molten Salt Hybrid	Underground Combustion or Hydrolysis
Heated Chamber Rotary Kiln	
Electric Rotary Pyrolyzer and Kiln	
Fluidized Bed	
Pusher Hearth	
Molten Metal	
Pyrolysis/Molten Salt	

Source: Shatto, 1983.

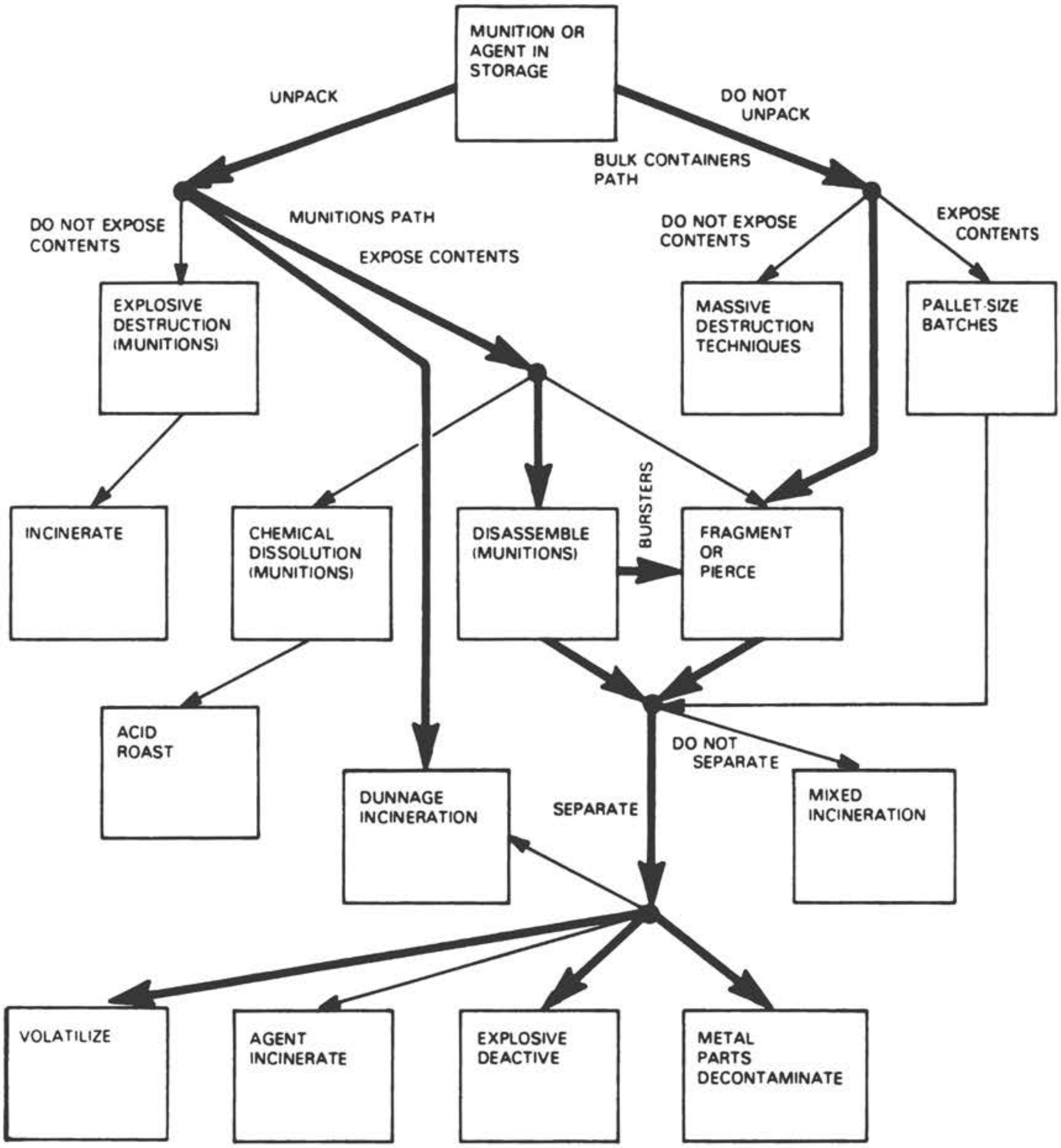

FIGURE 12 Preparation options for steady thermal destruction.

separated, the agent is volatilized from the projectile bodies and incinerated in a vapor burner, and the other material streams are thermally treated in three separate furnaces.

Rockets are removed from pallets (but not from their launch tubes), pierced and drained of agent, and sliced into five pieces. The agent and dunnage are incinerated separately. Solid pieces are processed first through the explosives deactivation furnace and then decontaminated in a heated conveyor.

One-ton containers, which are not packed, are sent through a three-chamber hearth furnace.* They are pierced in the first chamber. The agent is volatilized in the second chamber and is passed out to vapor fume burner. The container itself is thermally decontaminated in the third chamber.

The overall complexity of these processes is obvious. This has motivated the search for simpler technology. All four material streams (agent, explosives, metal parts, and dunnage) can be improved, but the best opportunities seem to lie in the areas of gaining access to the agent and explosives and in decontaminating metal parts.

Taking CAMDS and JACADS technology as the working base, improvements should aim to simplify the process by eliminating some of the operations. Local batch processing, for example, seeks to avoid the complexity of handling many individual items. Viewed as an individual step, unpacking is obviously more complex and costly than not unpacking. Similarly, processing an entire pallet seems less costly than handling individual items.

For these reasons, the Army's Technology Development Program has explored various batch handling concepts that might offer substantial savings over the one-at-a-time techniques now used. Because it is best to have a steady flow of materials at the point of combustion, however, local batch processing may not result in overall simplification or improvement. Further, batch processing may be less safe. A mishap with a batch could be larger than one with an individual item; and batch processing inherently provides less control over individual items.**

The following sections discuss a range of simplified operations, arranged roughly in order of increasing departure from current technology.

Improved Disassembly Systems

The current practice of mechanical disassembly should not be discounted too quickly in the search for improved technology for several reasons:

---

*This same furnace handles batches of projectiles for volatilization and decontamination.

**Steady flow to an end processor is, of course, not incompatible with upstream batch processing; one has only to accumulate batch output and meter outflow as desired.

- o It works.
- o It is not likely to determine the operating rate of economically balanced systems.
- o It is a necessary precursor to those downstream processes that can deal with only nonexplosive items.
- o When applied together with existing nonexplosive stocks, partial disassembly is well suited to uniform downstream destruction operations.

The JACADS design already includes substantial improvements over that at CAMDS. For example, simple shears are to replace circular saws for cutting M55 rockets. Similarly, linear conveyors are to be replaced by carousel-type machines more suited to rapid and precise operation (Parsons, 1983d; Parsons, Undated; Seat, 1984; USATHAMA, 1983a). Nevertheless, further improvements over current JACADS designs are both possible and desirable to achieve uninterrupted operation and to avoid difficult and hazardous maintenance work in toxic areas.

Systems to Avoid Sensitivity to Munition Variations

Munition disassembly, though feasible, presents some difficulties, particularly in achieving high throughput. Its many steps are all mechanically complex and subject associated machinery to wear and malfunction. Moreover, individual munitions vary and are sometimes unpredictable. For example, burster wells are occasionally welded-in--a feature that defeats the mechanical system designed to extract this normally press-fit component. Other problems include threaded connections that are difficult to unscrew and variations in assembly details that were not recorded during manufacture. Some, although not all, of these problems can be ameliorated, but they do add complexity and interrupt steady operation.

Even without munitions irregularities, the expected variations demand a significant variety of mechanical operations and disassembly devices. Many methods to expose munition contents have been explored in a search for a simple, reliable, and safe method that is insensitive to munition details. Pierce, saw, punch, drill, machine, and shear concepts have been examined (Battelle, 1982a; Carney, 1982; Davison, 1984; General Atomic, 1982; Houseman, 1984; Moynihan et al., 1983). DATS, for example, uses a drill (Hasson and Kolmer, 1978), and M55 rockets can be sheared open (Seat, 1984). Attempts to shear the thick-skinned, steel artillery projectiles, however, have not been encouraging, as might be expected (General Atomic, 1982; Carney, 1982).

Cryogenic fracturing is the most encouraging munition-insensitive entry system now foreseen. It has been demonstrated in preliminary tests on 155-mm projectiles (General Atomic, 1982). In addition to effectively fragmenting the shells into numerous pieces, the process was presumed to enhance safety through a substantial reduction in vapor pressure of frozen agent and possibly some reduction in the risk of explosion (General Atomic, 1982; MITRE, 1983c).*

If cryogenic fracturing could be successfully applied to steel-walled munitions containing both fuzes and bursters, it would offer even greater advantages over room-temperature processes.** The process has successfully fractured 155-mm projectiles containing bursters and simulated agent, but it has not yet been demonstrated on fuzed munitions (General Atomic, 1982).

As now envisaged (Davison, 1984), cryogenic fracturing involves unpacking individual projectiles, collecting them into batches for immersion in a liquid nitrogen bath, extracting individual projectiles from the bath by a pick-and-place robot that must reach through an air lock, and placing each projectile sequentially in an hydraulic press for fracture. Since projectiles are handled individually at the beginning and end of this process, the intermediate batch cooling seems inappropriate. The use of a relatively sophisticated and fragile robot adjacent to the fracturing press, where detonation could occur, also seems inappropriate. The process seems attractive and certainly worthy of continued development, but practical implementation remains to be developed. A simpler concept is suggested below (Figures 15 and 16).

Other concepts have been proposed to avoid sensitivity to munition details, including chemical dissolution and detonation of the projectiles' own explosive. These concepts do not warrant continued effort (see Chapter 10).

Systems to Avoid Unpacking

Several approaches have been pursued that avoid unpacking pallets. These include explosive piercing using shaped charges (Schultz et al., 1983), detonation in a "thermal tower" (Schultz et al., 1983), and cryogenic fracturing of entire pallets. The latter concept was mentioned briefly by one contractor, but not elaborated. In that case, batch cooling would be appropriate. Metered feed of the fractured product could provide a steady feed to an incinerator from the batch preparation. However, the desired steady feed would seem to negate the potential economy of pallet crushing in view of its greater risk.

---

*This assumption might not be valid because agent fragments would be scattered during brittle fracture and the entire surrounding area (unless refrigerated) would soon become wet with melted agent.

**Room-temperature shearing may open burster tubes, but it is also possible that ductile shearing will seal the fragments, and such violent deformation of a heavy-walled projectile might detonate the explosives.

Bulk Handling Systems

Concern with the relatively hazardous and costly task of destroying agents in munitions that contain explosives has largely overshadowed the problems of handling agents in bulk containers (i.e., 1-ton containers, bombs, and spray tanks). Punching such containers and draining their contents seems simple enough. In fact, even the heavy-walled, 1-ton container can be routinely punched by a simple mechanical device in the first chamber of the decontamination furnace for metal parts at CAMDS (USATHAMA, 1983a); however, the situation is, or at least appears to be, more complex.

Because some agents, mustard in particular, have solidified over the years, CAMDS was designed to volatilize the agent from punched containers and opened projectiles in the second chamber of the three-chambered metal parts decontamination furnace. Lacking better information about the stockpile details, this same furnace has been specified for JACADS and included in economic evaluations of baseline technology at all storage depots (Scott, 1984b; Shatto, 1984a).

Because the CAMDS furnace was designed to accommodate 1-ton containers and equivalent batches of opened projectiles, it is large and expensive. In fact, it is the most expensive single item in the entire baseline economic study (Scott, 1984b). Furthermore, the entire downstream air pollution control system must be sized for the peak load from this batch-type volatilization system. As a result, this single, oversize, costly furnace is far from the best for all but one of the eight depots in the United States (Scott, 1984b).

As an alternative, the Army is studying an electrically heated volatilization furnace system (Schultz _et al_., 1983). This design would incorporate several cylindrical furnaces whose alloy shells would be surrounded and heated by induction coils. After a bulk container has been pierced, it would be sealed in one of the furnaces and heated in an atmosphere containing less than 2 percent oxygen to prevent combustion. Vaporized agent is routed to a separate incinerator where it is destroyed. Wall temperatures are adjusted to maintain the vaporization rate as constant as possible. The temperature of the empty container is then raised to at least 538°C (100°F) for 15 minutes in an air atmosphere to burn out or decompose any agent residue and, thus, to decontaminate the metal parts. The processing cycles of the multiple furnaces are to be staggered so that the vapor incinerator receives an approximately constant flow of agent vapor, but the process seems more complex than necessary.

A recent Army study determined that all existing agents can be drained from their containers, thus eliminating the need for the slow volatilization process (Brankowitz, 1983). As a result, processing rates for drained agent might be roughly double those previously estimated for most items, with an attendant potential for cost reduction.

Agent drainage offers other operating advantages as well:

- o Volatilization from a large container in a massive hot furnace could not be stopped rapidly should disturbances require a shut down.
- o Liquid incineration could be controlled easily or even shut off.
- o A stored and pumpable liquid supply offers the opportunity to maintain desired incinerator conditions in the face of highly variable loading from other sources.
- o A controllable supply of agent enhances the prospect of using the material as a fuel for heating needs, such as metal decontamination.

In addition to reduced operating time, there is also a potential for substantial savings in capital equipment costs if the large, three-chamber hearth furnace can be eliminated at most depots. The consequences and potential for improvement, however, involve interactions between the requirements for destroying bulk agent and decontaminating the containers, as discussed below.

Decontaminating metal parts is simple chemistry--just heat them to more than 538°C (1,000°F) for at least 15 minutes. Mechanically, however, the procedure becomes complex if the metal parts are large. Rotary kilns have been selected for small metal-parts decontamination because they offer a proven, simple means to transport solids through the hot zone. As the parts increase in size, however, the durability of the kiln becomes a matter of concern. Thus, it is doubtful that a conventional rotary kiln could transport very large, cylindrical parts, such as 1-ton containers.

The high cost of a CAMDS-type, three-stage hearth furnace prompted pursuit of the induction-heated, volatilization system described earlier, but that system does not exploit possibilities for draining the agent.

SIMPLIFIED CONFIGURATIONS

In the course of its deliberations, the panel generated no substantially new approaches for disposal of chemical agents and munitions. In four areas, however, it suggests design improvements for consideration by the Army. The first two are merely simplifications of single machines; the last ones provide different design approaches that appear better suited to achieving steady-state system operations.

Simplified Burster-Well Extraction

With CAMDS technology, one gains access to the agent in artillery projectiles by pulling the pressed-in burster well from the projectile body. The empty burster well is gripped internally by an expanding collet. The smooth internal surface and small diameter of the burster well make it difficult to design a robust collet. At least one collet has failed in operations at Tooele. The critical nature of this operation and the hazards of maintenance in such a toxic environment call for a simpler and more reliable method.

One alternative is to heat the projectile and let the vapor pressure of the agent drive out the burster well. This already has been demonstrated, but the discharge velocity of the well was judged to be too high. Figure 13 illustrates a configuration believed to be more tolerant of a high discharge velocity. Furthermore, proper location and timing of the heat might reduce this velocity.

In this scheme, the inverted projectile would be held over a pool of agent and inductively heated near its midsection to vaporize the internal agent. After a suitable time, the projectile might then be heated rapidly adjacent to the press fit, causing relative expansion of the casing to ease the interference fit, thus releasing the burster well. The well and agent would both be expelled downward into the agent pool, where the well could be decelerated without damage to adjacent solid surfaces. Like the current mechanical system, this system would also be defeated by a welded-in burster well.

For processing small quantities of munitions, it might be economical to continue induction heating (though not while dwelling over the agent pool) for decontamination of the empty projectile.

Simplified M55 Rocket Shear

The rocket shear machine designed for JACADS (Parsons, 1983a, Parsons, 1983b) is a significant simplification over that of the early CAMDS facility (USATHAMA, 1983a), but further simplification is both possible and desirable. Figure 14 illustrates a gravity feed shear that would use only one moving part.

A combined shear and baffle would reciprocate through a fixed stroke, driven by a hydraulic cylinder or perhaps a crank. The rocket, in its firing tube, would be fed by gravity to be cut into segments of fixed length. Figure 16 also illustrates the desired shearing locations that would produce four segments of about 19 1/4 inches length and one, containing the fuze, of about 4 11/16 inches length (Seat, 1984). If the rocket were fed tail down and the distance between cuts were set equal to 19 1/4 inches, the desired pattern would be produced. None of the shearing locations appears to

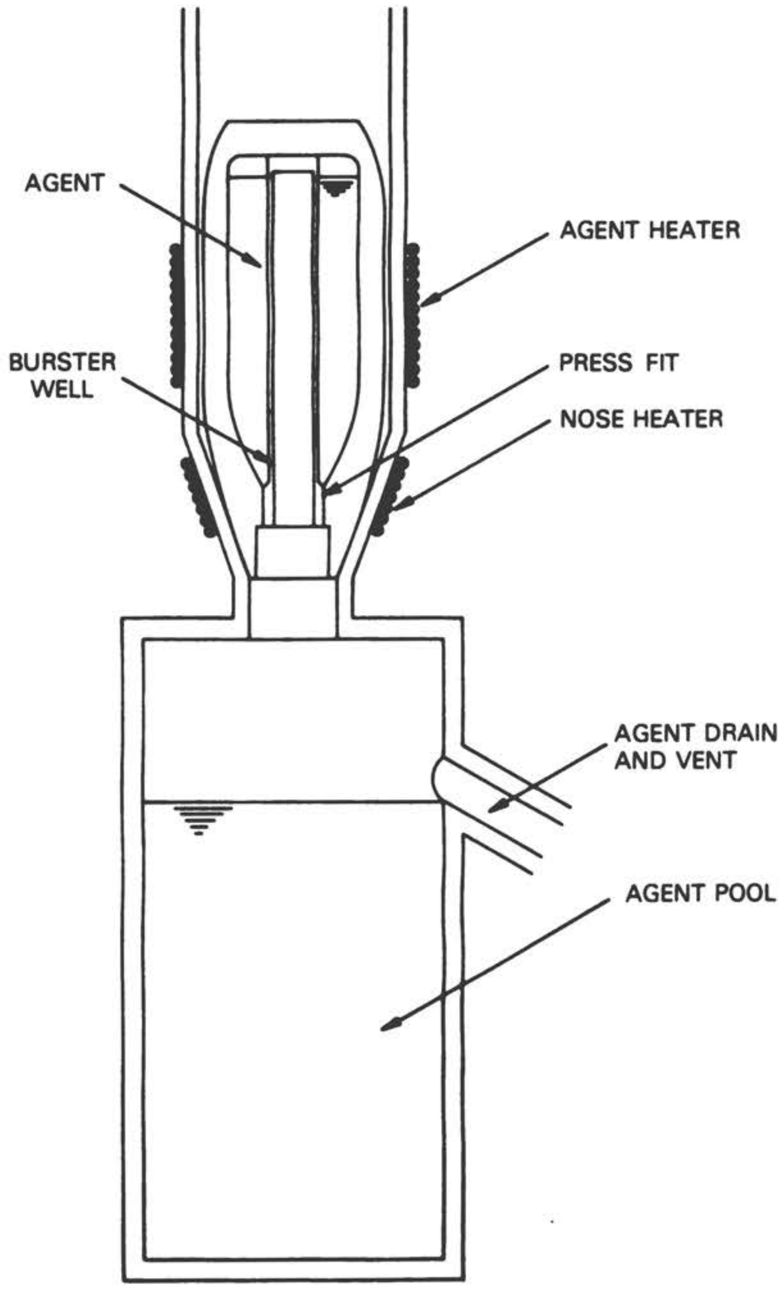

FIGURE 13 Vapor pressure expulsion of burster well.
Source: Technology Assessment Panel.

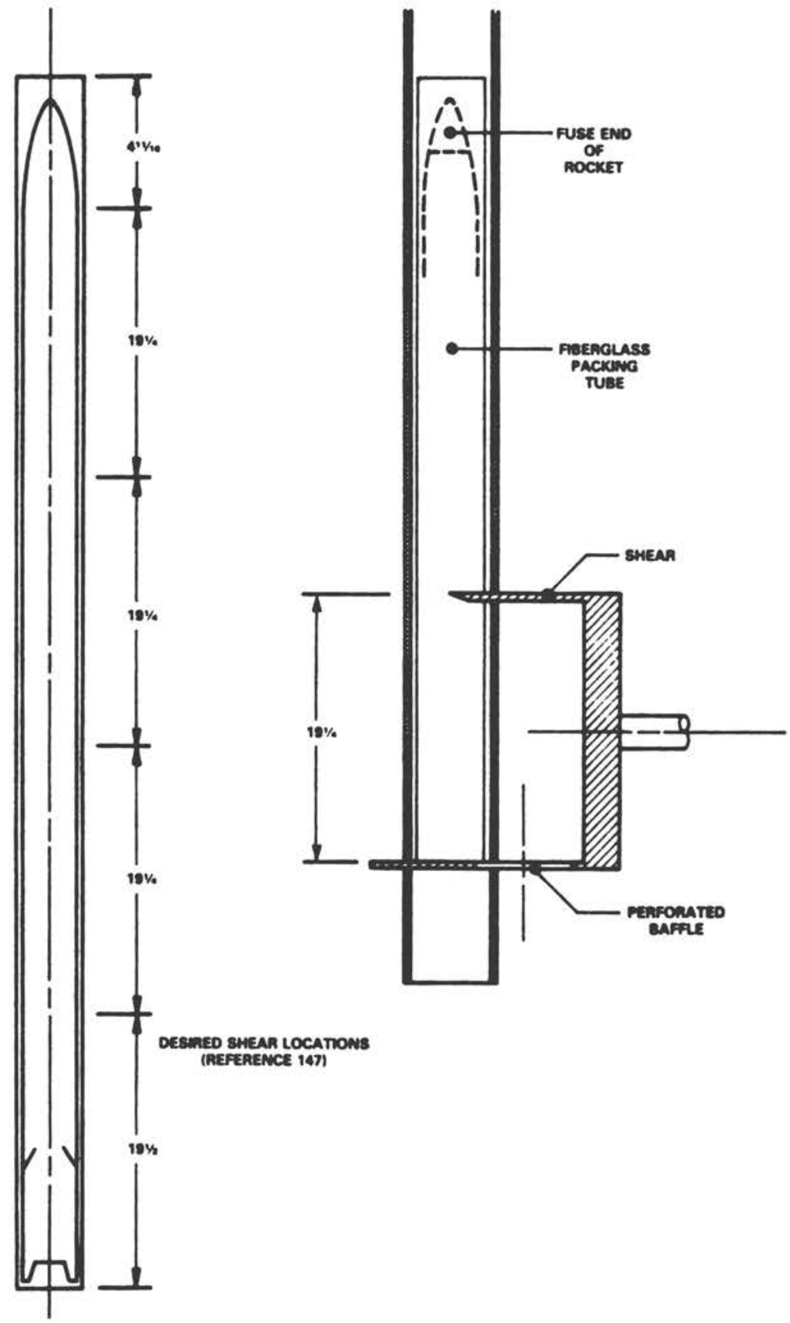

FIGURE 14 Simplified, gravity feed rocket shear.
Source: Technology Assessment Panel.

be critical except that if the top segment were too short, the shear might encounter the fuze.

In this design, cut number 3 is the first to penetrate the agent chamber and to shear the burster. When the fuze is separated by cut number 4, the agent would already have been drained from the region. In fact, if it is not attached at the fuze end or too deformed in shearing, the forward section of the burster will also have fallen out. If this occurs reliably and a small hole is provided in the baffle to pass it through, the last cut near the fuze might not be necessary.

"Steady Flow" Cryofracturing

The Army has decided to further explore cryogenic fracturing as a means for gaining access to the agent and explosives within projectiles. Cryofracturing is insensitive to munition details (Shatto, 1984b). The envisioned implementation of the concept (Carney, 1982; Davison, 1984) can be significantly improved. The system under consideration by the Army handles projectiles individually for unpacking, in batches for cooling, and individually again for fracturing. The transfer from batch cooling to individual fracturing is to be accomplished through a mechanical air lock by a pick-and-place robot. Because it would necessarily be adjacent to the fracturing operation, the robot would almost certainly be destroyed in an accidental detonation.

Figures 15 and 16 illustrate different stages of a simpler cryofracture system with only three moving parts: a projectile elevator, a blast door activated by the elevator, and the fracture hammer itself. Unpacked projectiles would be laid in a trough and would roll down when space became available. Progressing further, they would enter the liquid nitrogen bath and roll under the barrier wall. They are lifted individually from the bath by the elevator and again roll by gravity to the fracture device.

Only one projectile would be in the fracture room at any time. Fragments falling from the fracture device could be directed either into storage or into the incinerator. Since the blast door cannot be expected to provide a perfect seal against a detonation, a large vent should be provided behind the door to prevent blow-back of the liquid nitrogen to the loading side of the barrier wall.

This simple design offers the following advantages:

- Conveyors and sophisticated transfer machinery would not be needed.
- Steady feed to the nitrogen bath would avoid the violent boiling that accompanies batch feed.
- An air lock would be provided without moving parts.

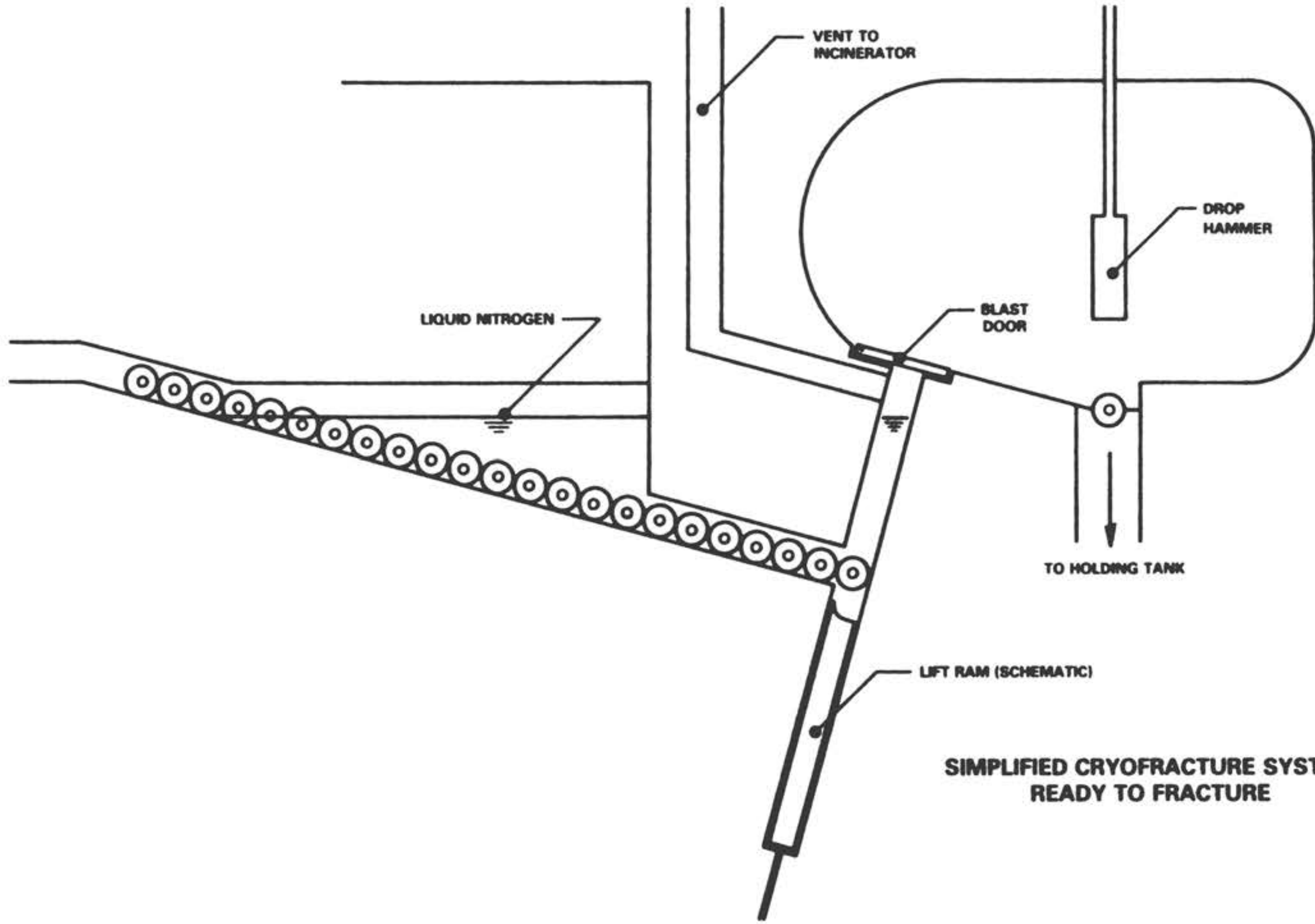

FIGURE 15 Simplified cryofracture system.
Source: Technology Assessment Panel.

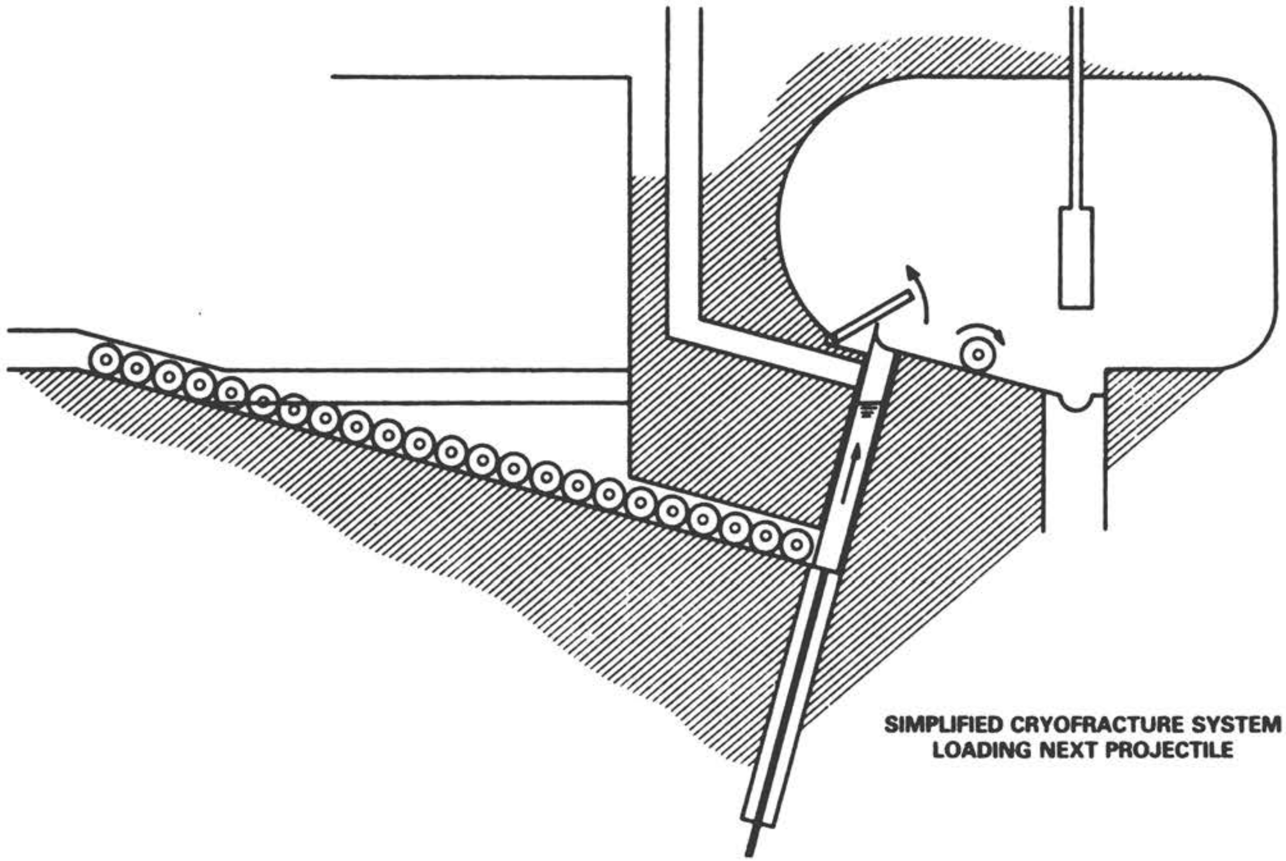

FIGURE 16 Simplified cryofracture system.
Source: Technology Assessment Panel.

- o The blast door would be entirely passive, activated only by the projectile elevator.
- o No machinery other than the fracture mechanism would be exposed to blast damage.
- o Components of the fracture mechanism located within the blast chamber could be extremely simple, perhaps even blast resistant.

"STEADY FLOW," REGENERATIVE BULK CONTAINER PROCESSING

Figure 17 illustrates a concept designed to provide a steady flow of both metal parts and agent while, at the same time, allowing for regenerative use of thermal energy. The basic furnace would be a heated tube, which takes advantage of the simple geometry of 1-ton containers. A counterflow of materials, with containers going from right to left and with agent, vapors, and air from left to right, could be maintained through the system.

Loaded containers would enter the system by rolling through an air lock (not shown) at the right end. They would be punched and drained there,* and then pushed in a line through the tubular furnace. As each container is emptied, it would be indexed to the left one-container length, advancing all containers in the tube. Another loaded container would be rolled in and the cycle repeated. The sloped, tubular furnace would permit continued drainage of agent to the agent sump as each tank moves forward and is warmed.

The containers would be heated in the central section of the furnace to achieve a "5X" decontamination condition. Although direct induction heating of the steel container is illustrated, indirect heating by radiation from a surrounding wall might be preferred. The wall could be heated inductively as in present experimental batch processes (Schultz et al., 1983), by combustion of fuel oil, or, in the ultimate system, by combustion of the agent.

While the sidewalls of the containers could readily be heated by any of these methods, heating their ends would be more difficult.** Figure 17 also illustrates heavy induction heating to bring the cylindrical walls to temperature, followed by local heating at the tank ends.

Once out of the heating zone, containers would meet a counterflow of cooling air. Heat extracted from the hot tanks by the air would be given up to incoming tanks upstream of the heating zone--hence the regenerative title. After preheating the incoming tanks, the air and agent vapors would be fed as the air supply to an incinerator or burner.

---

*Provision can be made to pressurize the containers with air to hasten drainage.

**Similarly, they are not so easily cooled, so adequate time at temperature may be readily attained.

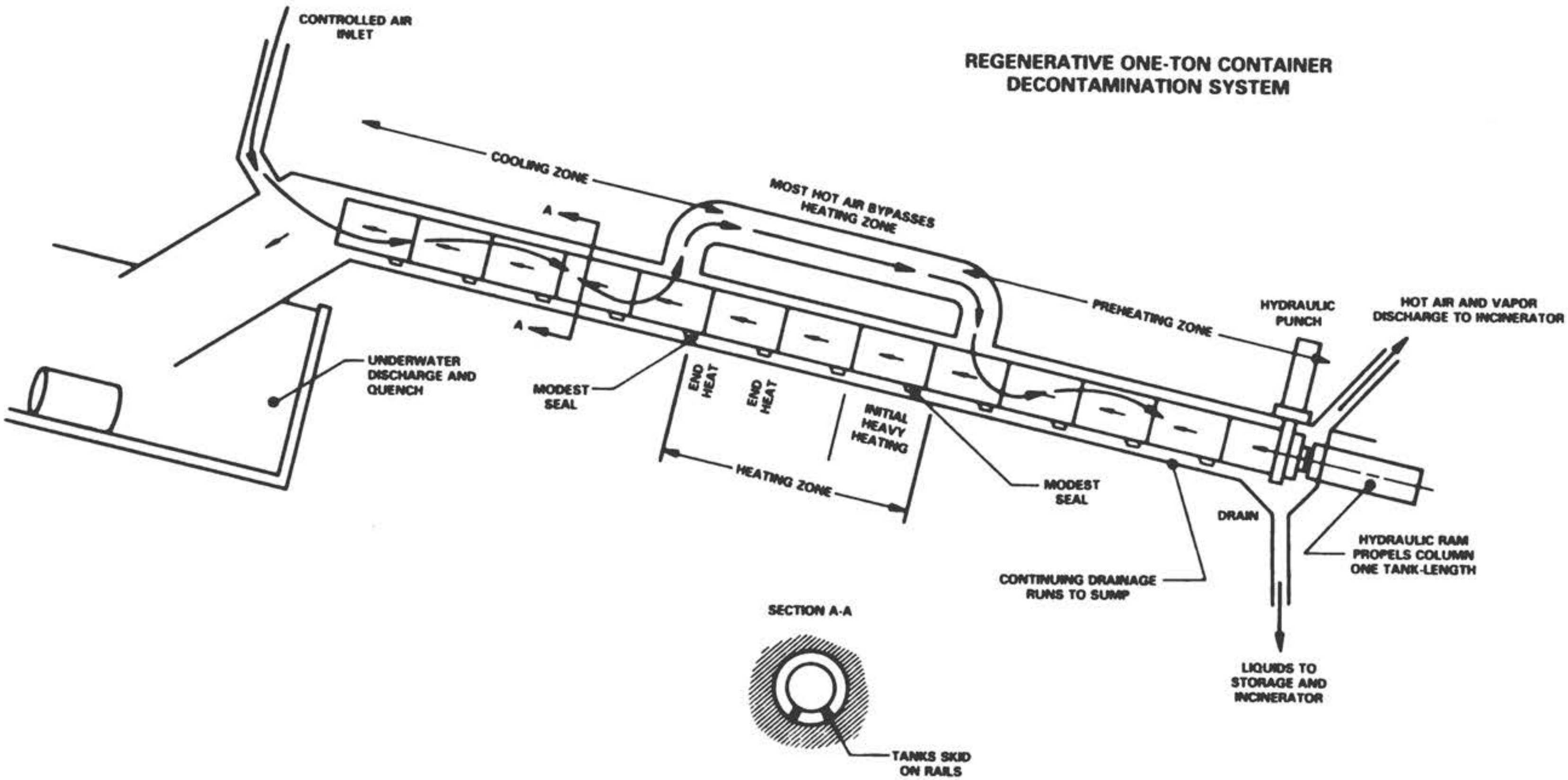

FIGURE 17 Simplified device for processing agent filled ton container.
Source: Technology Assessment Panel.

The regenerative feature offers three advantages: it would conserve expensive electricity (or other fuel energy) since much of the energy would stay in the system, it would raise the temperature within the agent combustion chamber (especially desirable if that chamber is to provide the heat source for decontamination to the "5X" level), and it might aid the drainage of incoming containers. It might be desirable to bypass most of the air around the heating zone, as illustrated, to assure high metal temperatures in this region.

Cooled, decontaminated containers would pass from the tubular furnace through a water-flooded air lock at the left of the figure. Other basically cylindrical items, including bombs and spray tanks, could also be processed in similar facilities. Perhaps even 8-inch projectiles could be decontaminated in such a facility.

The concept might be economically desirable for depots that have large stocks of 1-ton containers, such as Pine Bluff, Newport, and Aberdeen.* For small stocks, however, neither this single purpose furnace nor the larger hearth furnace of baseline technology is appropriate. Small stocks might better be handled by draining the agent for processing in a liquids incinerator and decontaminating the container by a modification of the in-shell combustion process first proposed for projectiles (Moynihan et al., 1983). In this process, the drained container could serve as its own combustion chamber for internal burning (air and fuel oil, for example) to provide "5X" decontamination.

---

*There are also large stocks at Tooele, but CAMDS already includes a furnace adequate to handle these containers.

15

System Safety

SAFETY: AN UNCOMPROMISING MANDATE

By design, chemical warfare agents are among the most toxic substances known. Munitions containing these materials must be handled so as to avoid exposure of workers, pollution of the environment, or exposure of the general population. For example, equipment and processes should be designed to prevent unintended explosions or agent releases and to safely contain them if they occur in any unanticipated way. In this regard, the Army's record has been very good.

Because of their extreme toxicity, no accident involving chemical agents is acceptable. Investigations by the Army or another agency into an accident will critically evaluate whether or not every reasonable and prudent effort has been taken and fully documented by the Army to anticipate and prevent such an accident. Reaction will no doubt be severe if the findings show that the latest means to prevent such an accident were not fully used. There should be no compromises in the system-safety program.

SCOPE OF SYSTEM-SAFETY ACTIVITIES

An effective system-safety program requires a precise description of the scope of activities to be undertaken, appropriate analytic techniques, and clear management practices.

The Army has defined the scope of safety activities for disposing of chemical agents in Military Standard 882B and its antecedents, Army Regulation AR 385-16, DARCOM-Regulation 385-3, and DARCOM-Regulation 385-23. Table 12 lists the elements of a general system-safety program; key elements are described in Appendix G.

MANAGEMENT PRACTICES

A sufficient number of qualified personnel should be available to perform system-safety activities, using analytic techniques such as those described in Appendix G. It is vital that the safety effort not

TABLE 12 Elements of Comprehensive System Safety Program

TASK	TITLE	TASK TYPE	PROGRAM PHASE CONC	VALID	FSED	PROD
100	System Safety Program	MGT	G	G	G	G
101	System Safety Program Plan	MGT	G	G	G	G
102	Integration/Management of Associate Contractors, Subcontractors, and AE Firms	MGT	S	S	S	S
103	System Safety Program Reviews	MGT	S	S	S	S
104	SSG/SSWG Support	MGT	G	G	G	G
105	Hazard Tracking and Risk Resolution	MGT	S	G	G	G
106	Test and Evaluation Safety	MGT	G	G	G	G
107	System Safety Progress Summary	MGT	G	G	G	G
108	Qualifications of Key System Safety Personnel	MGT	S	S	S	S
201	Preliminary Hazard List	ENG	G	S	S	N/A
202	Preliminary Hazard Analysis	ENG	G	G	G	GC
203	Subsystem Hazard Analysis	ENG	N/A	G	G	GC
204	System Hazard Analysis	ENG	N/A	G	G	GC
205	Operating and Support Hazard Analysis	ENG	S	G	G	GC
206	Occupational Health Hazard Analysis	ENG	G	G	G	GC
207	Safety Verification	ENG	S	G	G	S
208	Training	MGT	N/A	S	S	S
209	Safety Assessment	MGT	S	S	S	S
210	Safety Compliance Assessment	MGT	S	S	S	S
211	Safety Review of ECPs and RDWs	MGT	N/A	G	G	G
212	Software Hazard Analysis	ENG	S	G	G	GC

Notes: TASK TYPE

ENG - System Safety Engineering
MGT - Management

PROGRAM PHASE

CONC - Conceptual
VALID - Validation
FSED - Full Scale Engineering Development
PROD - Production

APPLICABILITY CODES

S - Selectively Applicable
G - Generally Applicable
GC - Generally Applicable to Design Changes Only
N/A - Not Applicable

TITLE

SSG - System Safety Group
SSWG - System Safety Working Group

Source: Appendix A of Military Standard 882B, U.S. Army be an exercise on paper only. System improvement can be accomplished only by timely analysis and a strong management effort to ensure that resulting recommendations are implemented to reduce costs and improve safety.

The Army's system-safety program should be subject to technical audit--a generally accepted practice. In view of the risks associated with the disposal of chemical agents, there should not only be internal audits, performed by the responsible safety organizations, but also an independent audit performed by a team including "outside" experts. Such a team should consist of both civilian and military personnel, including system-safety, human-factors, combustion, industrial, and mechanical engineers as well as toxicologists, public health specialists, and chemical and explosives experts. The team should have authority to perform unannounced inspections throughout the life of the disposal program.

SYSTEM-SAFETY AT CHEMICAL AGENT MUNITIONS DISPOSAL SYSTEM (CAMDS)

Since the experimental CAMDS facility has operated on a "fly-fix-fly" principle, the scope of its formal safety program has been limited. For example, failure mode and effects analyses were conducted on parts of the system (TRW, 1975; Hercules, 1974a, 1974b), but no documentation was provided to the panel regarding the timeliness and disposition of recommendations coming from those analyses. Further, there appears to be no on-going, formal system-safety analysis of design changes throughout the CAMDS project. Nor does there appear to be a formal hazard reporting and tracking system. The Air Force, Navy, and National Aeronautics and Space Administration (NASA) use computerized programs for such purposes.

The Army should establish such a program to improve integration of safety design efforts and to ensure that identified hazards are eliminated or controlled. This step is particularly important now as the Army prepares to move beyond the experimental CAMDS program into mature production facilities, yet to be designed, that will be operated by new people, yet to be recruited or trained.

Failure mode and effects analyses are usually considered to be inductive (bottom-up) procedures; however, the analyses performed for CAMDS (Hercules 1974a, 1974b) appear to have started by posing undesirable end events and then to have reviewed the components to determine how their failure modes could contribute to such events. They do not appear to have studied each component, one at a time, to identify how it might fail and what the effect might be.

A report by TRW (1975) found no single-point failures that might cause a catastrophic event. But, only half of the analytic process was undertaken, and that was only partially completed. There were no analyses of human performance under emergency or stressful conditions and no estimates of operator workloads. Since only certain of the facility's "building blocks" were analyzed and only inductive techniques were used, it is not possible to say with confidence that no single-point failures could exist.

In addition, the inductive approach was basically limited to equipment components. In one report, "manual operations" was included as a component, but without definition. The other analyses did discuss some human errors, but there evidently was no task analysis, no job safety analysis, and no step-by-step review of operator procedures or potential operator errors.

Thus, the failure mode and effects analysis for CAMDS was not complete. It should be completed--CAMDS can and should serve also as a pilot plant for experimenting with and developing methods for system-safety analysis.

Formal deductive and inductive analyses are needed on the potential for munition leaks and their amelioration. Evidently, leakers have occurred in numbers sufficient to cause some igloos to be sealed. Reportedly (Montel, undated), the agent concentrations within the igloo were too great to permit entry even by personnel wearing protective clothing. This suggests that in the event of a major incident, immediate corrective action might not be possible. Improved protective suits need to be developed and/or made available.

The routing of the leak-detection lines at Tooele appeared to be too long and circuitous to provide valid samples at the detector. Ventilation paths should be examined (if they have not already been) to ensure that vapor paths from potential leaks would not be drawn across operators' breathing zones. This is particularly important in those places where the breathing zone is not directly sampled and area detectors are used (see discussion on instrumentation in Chapter 11).

The safety record to date at CAMDS is excellent and a cause for justifiable Army pride. Nevertheless, a good safety record is no guarantee of future safety, particularly when the technology is used by operators other than those who have personally developed it with such care. The Army should improve and formalize its system safety by implementing a full scope of safety activities, including both inductive and deductive analytic techniques. The program should also include an analytic review of existing facilities, a hazard-tracking system to ensure that corrective actions take place, and review by an independent safety audit team.

System Safety for (JACADS)

The safety program for JACADS (Parsons, 1983c, 1983d, 1983e) is improved over that for CAMDS. The failure mode and effects analysis done for JACADS includes some human-error analysis, and there is a qualitative, deductive (fault tree analysis) effort in progress. The failure mode and effects analysis, however, was not preceded by a job safety analysis or a task analysis. No analyses carefully addressed emergency situations and operator overloads. Nor does the fault tree analysis consider interactions among equipment failures (i.e., it is a primary, not a secondary, tree).

The analysis is evidently still in progress and the documents provided did not resolve the tree to the component level. It needs to be completed to the component level before cross-checks can be completed. No listing is yet available of the paths by which a single- or multiple-component failure could lead to an undesired event.

Reliability data can be used to easily quantify those portions of the fault tree analysis that involve equipment failures only. Where human failures are involved, however, quantification is more difficult because appropriate conditional probabilities for human errors are often not available, although some data bases do exist. Where possible, the tree should be quantified and acceptable levels of risk defined.

There have been a number of computer codes developed for fault tree analysis and evaluation. These include: PREP, ELRAFT, MOCUS, TREEL AND MICSUP, ALLCUTS, SETS, FTAP, KITT1, KITT2, SAMPLE, MOCARS, FRANTIC, POCUS, SUPERPOCUS, ARMM, SAFTE, GO, GO "FAULT FINDER," NOTED, PATREC, PATREC-MC, BAM, WAM-BAM, WAMCUT, PL-MOD, COMCAN, COMCANII, COMCANIII, BACKFIRE, SRTPRN, FATRAM, SIFTARAN, NOAH, IMPORTANCE, IMPORTANCE II, BOUNDS, SPASM, TREDRA, MFAULT, RAS, FAUST, NSCAP, and CAUSE.

These include codes for qualitative and quantitative analysis, direct evaluation, common cause failure analysis, and importance assessment. Some codes involve sneak circuit analysis and software sneak analysis capabilities. The earliest such programs began in 1965, and improvements and innovations are continuing. Evidently, none of these analytic aids has been used to ensure the safety of the disposal processes used. A discussion of the general methodology used for these computer codes is found in Vesely *et al.* (1981).

The preliminary hazards analysis for JACADS showed the probability of a catastrophic failure to be extremely low, as is true for CAMDS. These analyses, to some extent, create a false sense of security, because no subsystem or system hazards analyses have been performed to pinpoint the likelihood that components might fail (e.g., alarms, detectors, interlocks, or controls), nor have the fault tree analyses gone to the component level. It remains to be seen whether or not the analyses will be carried to the necessary depth.

While JACADS is to use several robots, there is no evidence of careful consideration of the hazards associated with these machines. Robots are not intrinsically safe (Stowe, 1983). Provisions need to be made for pendant deadman switches, accessible emergency stop controls, physical barriers and guards, interlocked controls, limited speed modes, motion excursion limiters, "handcuff" capabilities, motion sensors, warning lights during dwell-time, power source lock-out, and avoiding shock-hazards. There should also be consideration of tool overload, explosion or fire potential, installation procedures, the proper training of all personnel, and the software/hardware interface. These and other considerations are discussed in the December 1983 issue of *Professional Safety*. The articles by Meagher *et al.* and by Potter are especially useful.

Such factors should be considered before any robots are procured or used. The reliability, maintainability, and safety of these machines are essential to the success of JACADS.

System Safety for the Expedited M55/M23 Program

The expedited M55/M23 disposal program apparently is relying on the safety record and hazard analyses performed for CAMDS and JACADS. This program includes its own appropriate and timely system-safety analyses.

Safety Organization for Oversight of Planned Disposal Systems

Figure 18 shows the Army's organization for overseeing the disposal of chemical munitions. The safety personnel are understood to be located as shown in Table 13. (Both Figure 18 and Table 13 are based on informal discussions with Army personnel.)

In addition to conventional armaments and explosives, including those of the Air Force and the Navy, the Armament, Munitions and Chemical Command (AMCCOM) also manages chemical weapons. It ensures that chemical accidents and incidents, including leakers, are investigated. USATHAMA is responsible for disposing of chemical weapons and agents. There is overlap in jurisdiction with the Depot Systems Command (DESCOM), which manages the five depots containing most of the stockpiled items. The safety personnel appear to be scattered by location and duty. They also seem to respond mostly to day-by-day requirements rather than conduct an integrated safety program.

The technical information needed for system monitoring should be reviewed. A review of this important document should be conducted to take into account policy changes or new knowledge that might develope over the last 15 years. Timely updating of important criteria documents and depot practices should be an integral part of the safety program.

The Army conducts safety audits and inspects the chemical weapons activities at all eight depots in the United States and on Johnston Atoll. So far, the practical safety record has been very good. There is, however, no independent audit team to ensure objective evaluations. Such a team should be established with the authority and clearances to conduct unannounced inspections and reviews. This arrangement should not only help prevent accidents, but also assist with any legal disputes that might arise if an accident were to occur.

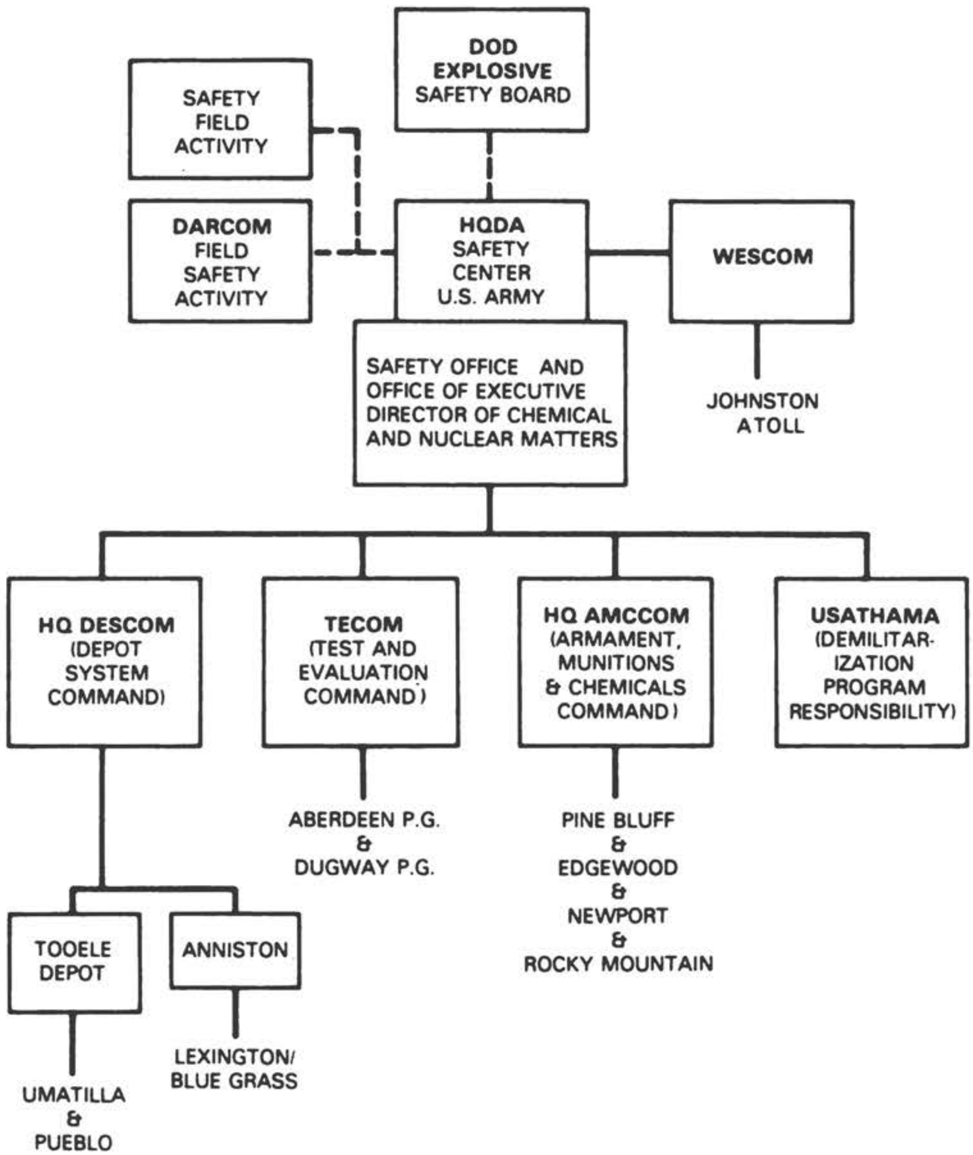

FIGURE 18 Army Safety Organization for oversight of chemical munitions disposal.
Source: Technology Assessment Panel.

TABLE 13 Location of Safety Personnel with Chemical Weapons Responsibility

LOCATION	NUMBER OF PERSONS
DOD Explosive Safety Board	1
HQ DARCOM	1
Army Safety Center	None
DARCOM Field Safety Activity	2
WESCOM	Unknown
HQ DESCOM	1 (Vacant)
TECOM	1 Part Time
HQ AMCCOM	3
USATHAMA	4 Chemical Agent Personnel
Umatilla	1
Pueblo	1 Technician 1 Intern 1 Safety Professional
Tooele	2
Anniston	1 Full Time 2 Part Time
Other	Cannot Estimate

Source: Technology Assessment Panel

16

Human Factors Considerations

MIL-H-46855B, MIL-STD-1472C, and Army Regulation 602-1 establish the requirement for including human factors considerations in the development and acquisition of Army systems. As used in this report, "human factors" refers to those features of the human-machine system, including training, that affect operator or maintenance performance or error potential, which, in turn, can affect productivity and safety.

The specific considerations addressed here include:

- Allocation of functions to human or machine--typically, the question of whether the person is local or remote in the system and the level of automation.
- Task analysis--a delineation of the specific tasks people will be required to perform to accomplish their assigned functions.
- Human-machine interface--the design of the hardware or software interface with the system personnel. Implicit in this effort is the use of task analysis to determine specific information and response (controls) people need to perform their tasks under normal and emergency conditions.
- Training--the most common and accepted technique for improving competency (often very expensive).
- Procedures or job aids--documentation at the job location to guide or support the performance of selected tasks.

GENERAL HUMAN FACTORS REQUIREMENTS

Allocation of Functions (Automation)

Automation, as well as remote control and handling, plays a key role in reducing the potential for contaminating the employees of chemical munitions disposal facilities or nearby residents. It is also important to minimize the potential for human error or degraded personnel performance, which, in turn, could affect the disposal process. This requires careful design of process functions and consideration of the human's role.

The notion of allocation of functions is found in a few instances in design requirements and documentation (e.g., see Parsons, 1983f and RFP DAAK11-84-R-007). It appears, however, that the allocation of functions and automation design in present or planned projects have not resulted from deliberate attention to human factors. Rather, those functions that cannot be performed by a human because of health or safety considerations either have been "automated" or designed for remote control. Moreover, what is referred to as "automation" is frequently no more than remote control with operators actively participating in the loop.

Further, neither human-factors methodology nor criteria appear to have been used to allocate those functions that can be implemented either by some combination of human and machine or by humans alone. No formal analysis of human factors has been performed that would develop essential information and response capability (instrumentation and controls) needed to perform those functions allocated to the humans or to monitor and intervene in these functions, when needed.

Except for detecting some malfunctions and diagnosing faults, maintenance appears to be viewed as a manual process. Most maintenance functions will be carried out by personnel wearing protective suits, known as demilitarization protective ensembles, and using both special and conventional tools and test equipment. Thus, the primary human-factors considerations for maintenance should occur during the human-machine interface design efforts.

A final and perhaps most important consideration with respect to automation and allocation of functions is the human role during emergency or upset conditions. As with most other complex systems, these process functions apparently will have a reasonable amount of redundancy and fail-safe design. Nevertheless, there probably will be occasions when operators are the primary means of controlling an emergency condition. In such cases, they will need adequate instrumentation and controls to accomplish emergency functions, even if the probability of these events is extremely low.

Task Analysis

An analysis should be performed of which functions are allocated to humans and which to machines. This is necessary to derive and document the required human performance (tasks) in terms of skill, knowledge, and the information and response required to accomplish the task.

Apparently, no documented task analysis has been performed or is planned for any of the chemical munitions disposal programs. Task analyses are needed to provide a basis for selecting personnel, developing training requirements, specifying procedures or job performance aids, and designing the human-machine interface. There is no substitute for an adequate task analysis if performance is to be optimized and errors are to be minimized.

Human-Machine Interface

Human engineering and the human-machine interface have received the most attention to date. Some work has been done for both CAMDS and JACADS, and it is called out as a requirement in the Army Request for Proposal for the Advanced Chemical Demil System Development (RFP DAAK11-84-R-0007). Both the work that has been done and that which is called for are generally based on MIL-STD-1472c, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities. This standard is well developed, but there is no indication that it or other criteria have been or will be used in the actual design process.

In the area of instrumentation and controls, human-factors engineering must deal with more than the perceptual-motor interface alone. A task analysis is required to determine what specific information and response capability (cognitive interface) are required by operations personnel to perform explicit tasks under normal and upset conditions. Such an analysis should provide the basis for evaluating the adequacy of the instrumentation and controls, assessing operator workload, and designing the best work stations.

Many of the human factors requirements, methods, and criteria developed for commercial nuclear power plants in recent years would be applicable to a review of the human-machine interface at sites such as CAMDS and JACADS or other new facilities (e.g., NUREG-0700).

Training

Training is the most commonly accepted technique for developing or improving performance capability. It should be developed using some form of "instructional system development" (U.S. Navy, 1975). This technique has been formalized over many years and proven to be a cost-effective method for developing training programs that are criterion-referenced (competency-based). It should help identify appropriate learning objectives, training media and settings, and materials and devices.

Disposing of chemical munitions requires highly trained personnel, particularly in preparing for emergency or upset conditions. To be most cost-effective, however, training needs to be integrated with the use of procedures, job aids, or human interface design to achieve best performance. Investments in procedures, job performance aids, and human-machine interface design become part of the system. Training, on the other hand, is invested in individuals and is lost whenever personnel turnover occurs.

Training plans have been developed or identified as requirements by USATHAMA for all of its projects to dispose of chemical weapons. It does not appear, however, that these plans were or will be developed according to any formal instructional system development process or based on task or job analysis. This is not a serious problem at CAMDS, where many of the personnel helped to design and build the system. In other disposal operations, however, there will be no "old timers" to build on. In those cases, training will be crucial; new and inexperienced people will need to be brought in and expected to perform effectively.

Procedures or Job Aids

Procedures (i.e., technical documentation or instructions) are an important part of operating any complex process. They tell people how to perform infrequent tasks and how to respond to low probability events. A detailed task analysis is the best basis for initiating procedure development.

The Army has spent almost 15 years developing the "Army New Look" manual, which is now known as SPA (Skill Performance Aids) and formalized in MIL-M-63036 (TM). This approach reduces performance time and errors. In fact, much has been learned about procedures and their effect on human performance, and there are established guidelines and criteria for the format and presentation of procedures (e.g., Hatterick and Price, 1980). This knowledge should be used in designing disposal procedure.

In recent years, microprocessors and flat panel displays have led to developments in computer-based information systems, including interactive systems, for supporting individuals in their jobs. The prospect of using these more innovative techniques should not be overlooked.

Other human factors considerations that could affect human performance include personnel selection, job design, effects of shift work, and the impact of decisions on whether or not munitions and agents are to be transported to regional depots.

HUMAN FACTORS IN CURRENT OR PLANNED PROJECTS

Human Factors Considerations at CAMDS

Because CAMDS is continually evolving, there apparently has been no formal effort to allocate functions and determine the optimum role of personnel with respect to productivity and safety. Most materials are handled either manually or by using forklifts, hoists, and pick-and-place robots. Most maintenance is carried out manually. In toxic areas employees wear the demilitarization protective ensemble (USATHAMA, 1983a).

Also, because CAMDS is an experimental facility, it appears that no documented task analysis was done. Such analyses will be needed to provide the basis for developing training requirements, procedures, and the human-machine interface design of future production-type facilities.

A human factors analysis was conducted for the agent destruction system at CAMDS in 1974 (Jones and Albaugh, 1974b). This analysis was limited to the human-machine interface. Numerous problem areas were identified and recommendations made for their resolution. The panel has no way of verifying whether these recommendations were carried out. The analysis was based on early concept design drawings, and the report recommended that an analysis of the final fabrication and installation design be performed. This does not appear to have been accomplished yet.

The equipment and facilities at Tooele show that, in some form, every classical man-machine interface problem exists at CAMDS. These problems include instruments that cannot be read, inadequate signage, temporary labels and colored tape strips to aid identification and instrument relationships, and controls that go the wrong way (e.g., moving switches down instead of up to turn equipment on). Taken together, these discrepancies represent a greater potential for operator error than is necessary; however, the net productivity and safety consequences of such deficiencies could not be assessed by the panel.

A training program has been developed for CAMDS (Lurk, 1981), but there is no evidence that the training plan was developed with a formal, instructional systems development approach. None of the training materials furnished to the panel has well-defined learning objectives. In view of the continually evolving, experimental nature of CAMDS, training is accomplished primarily by classroom instruction and over-the-shoulder learning on the job. No extensive use is made of simulators or training devices. It is not clear what training is given for low probability events that could have serious safety consequences.

The technical procedures at CAMDS tend to be event- rather than symptom-oriented. These procedures might cover most situations, but some events might occur for which there are no procedures. Also, there might be upsets for which the cause is not apparent. In either case, personnel must rely on skills acquired from training or on the human-machine interface design and the adequacy of instrumentation and controls.

JACADS

The panel was briefed on JACADS by Ralph M. Parsons Company and by USATHAMA. It also reviewed the final design concept documentation. Since the design is still evolving, however, and since construction is not scheduled to begin until 1985, no observations of actual equipment or facilities could be made. From the human-factors point of view, the JACADS design differs from CAMDS in the following ways:

- o JACADS is to have substantially more automation and less direct handling of materials by personnel.
- o An integrated instrumentation and control system is to be provided, and most functional areas are to be monitored or controlled from a centralized control room.
- o There are observation corridors with local instrumentation to be used for direct viewing of various process functions or equipment.
- o The processing rate and the number of personnel required to operate the facility are to be considerably greater than at CAMDS.

Neither the high level of automation nor the centralized control design imply that a minimum skill level of operating personnel is adequate.

JACADS planners have recognized the need for human-factors considerations in the design and development of the processing systems. This is evidenced by the development of a human factors engineering criteria document (Parsons, 1983f) for the design and development of processing systems, equipment, and facility interfaces. The criteria and guidelines in this document are well organized, and they are based on recent and relevant standards and criteria from the military and the commercial nuclear power areas. They are limited, however, to human-machine interface considerations. While the allocation of functions is addressed briefly, no specific methodology or criteria is included.

There are, of course, requirements that are unique to JACADS, such as areas in which the demilitarization protective ensemble must be worn, for which the human-factors engineering criteria were not empirically derived. Nevertheless, these criteria seem to have been reasonably and logically developed, and are generally well stated in the document (Parsons, 1983f).

The human-factors engineering criteria developed for JACADS apply to the human-machine interface primarily in the human perceptual-motor or anthropometric area. These criteria can be applied to certain interfaces, such as work-space design, work environment, and design for maintainability, more or less independent of the required task performance.

In the area of instrumentation and controls, the application of human-engineering criteria to the control and display design is not, in itself, enough to ensure the best performance. It is also necessary to consider what specific information and response (controls) are needed to perform explicit tasks under either normal or abnormal conditions. No task analysis has been done that can serve as the basis for deriving these requirements, and there is no assurance that adequate instrumentation and controls will be available in the control room. This includes consideration of emergency or upset conditions and the information needed to make decisions during such conditions as well as the controls, communications, and procedures needed to implement them. Finally, there appears to be no documented analysis to provide the basis for the design of the control room or to determine the number of work stations and personnel required for effective operation.

As at CAMDS, maintenance at JACADS will be primarily manual. It, likewise, will require entry into the facility in special protective suits. No documented task analysis has been performed for JACADS operations or maintenance. Nonetheless, personnel positions have been identified and the preliminary instrumentation and controls have been determined.

An analysis of specific training requirements should be conducted for JACADS. Since the skill demands for maintenance and operations personnel are likely to be unusual, training is essential for a cost-effective and safe operation. Training is scheduled to take place from August through November 1988. In view of the time required to prepare training materials and equipment, planning should begin now, particularly if a task analysis has to be done.

No information was available with respect to procedures or job performance aids for JACADS operations or maintenance. Specific procedures should be developed for both normal and emergency operations as well as for maintenance.

The Technology Development Program

Except for CAMDS and JACADS, none of the R&D concepts for handling materials and destroying munitions and agent has been sufficiently well developed for this panel to assess the human-factors considerations and their implementation. The panel notes that the Request for Proposal dated November 3, 1983 for the Advanced Chemical Demil System Development contains the following paragraph (page 15):

> (b) Human Factors Engineering (HFE). HFE analysis shall be performed to ensure that the RAM and safety of the system is not degraded through human activities during operation or maintenance. HFE program requirements shall be accomplished through the use of established HFE design criteria and practices based on MIL-STD-1472. The contractor shall perform allocations of functions to personnel, equipment and human-machine combinations based on analysis and trade-off studies, including factors such as: required sensitivity, precision, time and safety; minimum number of skills required to operate and maintain the system; and time-cost performance.

If this requirement is carried out fully, it will clarify some human-factors considerations. The requirements for task analysis, training, and job performance aids were not specified in the RFP, but might be accounted for later.

GOVERNMENT VERSUS CONTRACTOR OPERATIONS

The panel has conducted a cursory examination of whether the disposal facilities should be government-owned and contractor-operated or government-owned and government-operated. No conclusions are offered; this management question is left for the Army to decide.

17

Transportation Safety Considerations

At the beginning of its study, the committee had hoped to make a definitive statement about the relative risks and costs of (a) continuing to store and ultimately to destroy the stocks of chemical munitions and agents at their current storage depots, or (b) transporting some of them to carefully chosen consolidation sites, which could reduce the number of disposal facilities to be constructed. Such shipments might be justified if the net risks involved in shipment, storage, and destruction at a few depots were clearly lower than those of storage and destruction at each of the current sites--considering workers, neighbors, and people along the transportation route. If the risks of transport are acceptable and not greater than those of keeping the munitions where they are now, then decisions based on minimizing costs can be made without jeopardizing safety.

The data required for such comparative safety-hazards-risk assessments are not available. Clearly, the Army needs solid, professional, and independent assessments of the relative risk and cost of disposing of chemical agents and munitions on-site versus transporting them for destruction at regional sites. Assessment of transportation factors was not the responsibility of this panel.

The two principal transportation studies that have been completed are contradictory. In 1982, General Atomic Company studied off-site transportation of chemical munitions and agents (General Atomic, 1982). The study analyzed the items to be shipped, four transport modes (air, highway, water, and rail), and the distances involved. The study used current public laws and regulations, plus hypothetical accidents to determine how shipping containers should be designed. The study identified and evaluated containers that could enhance safety. The one selected as best, an integrated overpack concept, CAMPACT, was described in detail and analyzed for life-cycle cost, possiblity of design limits being exceeded in an accident, and its ease of handling.

The General Atomic report recommended:

> Truck transportation using the CAMPACT is the least costly and safest transportation mode. Further study is required to evaluate the effects of escort requirements and sociopolitical considerations on this conclusion. Air shipment with CAMPACT protection is not cost effective and does not improve accident safety (neglecting an evaluation of the relative consequences of an agent release).

In 1983, the Oak Ridge National Laboratory (ORNL) studied some transportation alternatives for regional disposal of chemical weapons (Shappert et al. 1983). This detailed cost analysis focused on moving all items to a single depot (Tooele) or to two regional sites (Tooele and Anniston). It compared rail, highway, and air transport, and dealt in detail with institutional situations.

The ORNL report stated:

> The maximum costs of shipping chemical warfare (CW) stocks occur when air is used as the preferred mode of transport and are minimized when rail is used. Costs are also minimized when the alternative of using two regional sites is considered, as opposed to one national site because the total number of ton-miles is reduced. The additional advantage of utilizing two regional sites is that two plants can process the CW materials at a faster rate, thus completing the overall demilitarization program more rapidly. By reducing the number of ton-miles required to transport all stocks to the processing sites, public exposure would be reduced. The potential of terrorist attacks during the shipping phase would also be decreased.

Further, the report recommended that, "In any case, the [Rocky Mountain Arsenal] should be considered as one viable option for handling the Pueblo material." The Army, however, has already experienced substantial problems with nerve agent stored at the Rocky Mountain Arsenal (U.S. Army, 1981). Thus, as a result of protests by Denver area residents, Congress (PL 96-418) required that all chemical munitions be removed from that arsenal. The munitions were finally flown to Dugway Proving Ground and trucked from there to Tooele. The move was challenged by Utah groups in court, but the court ruled against them. The total cost for moving 888 items was approximately $6 million (Carney, 1984).

Residents around the Lexington-Blue Grass depot seem to be vigorously opposed to having a disposal facility located near them. For example, the Madison County Fiscal Court, at its March 5, 1984 meeting, asked the Army to safely transport any nerve gas stored at the Lexington-Blue Grass Depot to an area less densely populated for storage or disposal, or to explain why it cannot be safely transported (Botner and Wagner, 1984).

Neighbors of other chemical munitions depots might also prefer that disposal be carried out elsewhere. Disposal anywhere might seem safer than nearby disposal, if one bases the conclusion upon desire and neglects risk in local and/or long-distance transport; but there is risk in transport too. The key issue is whether the total risk of transport and disposal at another depot (or continued storage) is less than the risk of disposal at a given current site without transport.

All off-depot transport of chemical munitions subsequent to the enactment of PL 91-121 has been carried out only after thorough planning and approval by the Surgeon General of the United States (Staniev undated a and b; Griffin 1981; U.S. Army, 1981 a and c). The last shipment prior to PL 91-121, known by this panel, was to the Military Ocean Terminal at Sunny Point, North Carolina, where rockets packaged in steel-enclosed concrete vaults were loaded aboard the S.S. LeBaron Russell Briggs for ocean disposal on August 18, 1970 (Ferer, 1975). All such movements were made safely.

As discussed earlier, however, a good safety record in itself is no guarantee that a serious accident will not occur during future transportation operations. Further, the situation has changed since those shipments were made. For one thing, terrorism has increased dramatically. In addition, the general public and citizen activist groups have displayed increased concern about chemical munitions and agents either being located near or transported through their communities, let alone brought there from elsewhere for processing.

The Army should examine both the General Atomic and the ORNL approaches and adjust them to the same assumptions and cost parameters to determine which transport mode (rail or highway) really is cheaper. More importantly, neither of these studies adequately defined the risks of transporting chemical munitions and agents. Nor have several analyses (Katz, 1974; Jones and Albaugh, 1974a and b; U.S. Army, 1981a and b) assessed the hazards and risks associated with on-site disposal or long-term storage.

Therefore, no meaningful comparison could be made between the risks of on-site disposal and those involved in transporting chemical munitions for centralized disposal. An adequate study would need to consider the possibility of accidents that have high probability rates with relatively minor consequences as well as those having low probability rates with very severe consequences. Such an analysis should recognize that the socio-legal-political constraints on transportation are emotional, interdependent, and substantial. A great deal of convincing will be required before an Army proposal for transporting chemical weapons will be approved. Indeed, considerable delay can be expected.

The conclusions from such a transportation safety analysis would no doubt be controversial and inconclusive, and the decision whether to transport or not would almost certainly be made on grounds other than hard evidence. Nevertheless, to avoid delay caused by debate over the need for better information, the Army should assess the risks of transporting chemical agents and munitions for centralized disposal (e.g., at Tooele and Anniston). This will give the Army the best comparative information when it is needed.

Further, both the Aberdeen and Umatilla depots border on navigable waters (the Chesapeake Bay and Columbia River, respectively). Thus, it would be physically possible to load their stocks onto U.S. Navy vessels for transport to and eventual disposal on Johnston Atoll. Additionally, Tooele is only 500 miles from Umatilla; its stocks might be sent to Umatilla for later shipment to Johnston Atoll.

18

Findings, Conclusions, and Recommendations of the Technology Assessment Panel

TECHNOLOGY

Thermal destruction of chemical agents is preferred over chemical neutralization, disposal by nuclear explosion, placement in the deep ocean, or other methods studied by the panel. Several findings support this conclusion.

- Chemical neutralization of agents is both slow and expensive. It produces a large quantity of hazardous salts that must be either stored or destroyed. The process is not suitable for destroying mustard agent. While GB can be converted into methyl phosphonic difluoride (difluro), one of the components of binary weapons, commercial processes are more economical. Moreover, the Army's need for difluoro has not been established.
- Disposal by nuclear explosion would be a fairly simple process that does not require munitions to be either unpacked or disassembled. It does, however, involve additional risks and political difficulties of transporting chemical weapons to some as yet undetermined sites for underground destruction. Sampling programs would be needed to verify exactly what had been destroyed.
- Placement in the deep ocean is not compatible with current laws. The magnitude and extent of the agent's ultimate effects on the environment are not known. Some stocks, such as those at Tooele, would need to be transported more than 500 miles before they could be placed aboard ships.
- Incineration, on the other hand, is probably less expensive than any of the preceding three major options. It has been successfully demonstrated for all four chemical agents in the stockpile. No off-site transportation of agents would be necessary. The process can be carefully controlled.

- o The Army conducted a very thorough search for and evaluation of novel and alternative destruction methods, but identified no better approach.

Near-Term Programs

Three specific disposal programs are currently under way or well along in planning: BZ disposal at Pine Bluff Arsenal, the expedited M55 rocket program for several depots, and the Chemical Agent Disposal System planned for Johnston Atoll (JACADS). Based on the following findings, the M55 rocket and BZ disposal programs should not be delayed to await improved technology.

- o Obsolete and unserviceable items constitute a greater hazard than other items in the stockpile and the need for prompt disposal has already been established.
- o Much design work and experimental verification have already been completed.
- o Mechanical processes for shearing rockets at room temperature are simple, inexpensive, thoroughly proven, safe, and reliable.
- o The current thermal destruction processes are also simple, effective, and proven at the pilot scale.
- o Since aluminum does not become brittle at cryogenic temperatures, cryofracture of M55 rockets will not work.
- o For those depots where M55 rockets are stored, the quantities are large enough to warrant on-site disposal.
- o There is no evidence that waiting 1 or 2 years for the development of advanced technology will result either in lower overall costs or reduced risk to the health and safety of the workers or the public.

The disposal of M55 rockets and BZ should not be delayed either by attempts to force transport of rockets from existing locations for disposal elsewhere or for further, possibly inconclusive, studies of transport options.

The JACADS facility is to be equipped initially for an expedited program, but built large enough to dispose of the entire Johnston Atoll stockpile. Disposal of the remaining stockpile might provide an opportunity for early application of some of the developing new technologies discussed below.

Recommendation: The Army should proceed promptly with the construction of facilities for safely disposing of M55 rockets at their existing storage sites. At the same time, the Army should give due consideration to such design improvements as simplified shearing devices and decontamination furnaces that avoid rotary seals, as well as other design improvements that become evident as the program is implemented. Facilities designed for disposing of M55 rockets should provide for the subsequent, economical installation of additional and/or more advanced equipment needed for safely and efficiently disposing of other chemical munitions stored at the particular depot.

Bulk Container Processing

It appears inadvisable to use the large, three-chamber furnaces designed for baseline technology for volatilizing agent from bulk containers.

- Volatilization is slow and unnecessary.
- The equipment is large, expensive, and not well suited to other stockpile items.
- Batch volatilization affords poor control because it is a very unsteady operation that cannot be shut off rapidly.
- Simpler alternatives are available for decontamination of large containers.

Two alternative thermal decontamination approaches have been suggested: regenerative system and a modified "in-shell" combustion process first proposed for processing projectiles.

Recommendation: The Army should further explore such alternatives as punching and draining these containers with subsequent combustion of the agent in controlled-feed liquid incinerators (perhaps along with agent drained from munitions). Simpler decontamination procedures should be developed or, alternatively, containers might be chemically decontaminated, crushed to reduce their volume, and shipped safely to a central site for final heat treatment or possible ocean disposal.

Artillery and Mortar Projectile Processing

Cryofracture appears to provide significant advantages over munition disassembly as a means of gaining access to agent and burster, at least for artillery projectiles and perhaps for mortar rounds.

- It is not sensitive to munition size and design details.
- It reduces the size of parts to be fed to the incinerator.
- It allows steady, metered flow to the incinerator.
- It permits a smaller incinerator and air pollution abatement system, and reduces the requirement for explosion containment.
- It uses no fragile components; e.g., tools, saws, drills, collets.

Little detailed system design has been completed for cryofracturing systems, but the technique seems to lend itself to simple and robust design.

Recommendation: The Army should support further study of cryofracturing to resolve the remaining uncertainties. These include (a) the probability of burster detonation, (b) the ability to safely handle fuzed munitions, (c) additional design simplifications, and (d) determining the size of fragments for possible simplification of downstream transport mechanisms and decontamination furnaces.

Design Simplifications

The equipment at the Chemical Agent Munitions Disposal System (CAMDS) is more complex than would be desired for production-type disposal facilities. It offers numerous opportunities for design simplification. To a lesser extent, the same may be said of JACADS. This conclusion is supported by the following findings:

- CAMDS was developed for experimental flexibility and has grown through piecemeal modifications.
- JACADS has inherited much of its design directly from CAMDS and is an assembly of separately developed components and systems.
- Design philosophy has deliberately and properly emphasized the use of proven components, many of which were not developed specifically for disposing of chemical agents.
- Recent tests have shown that some design assumptions (e.g., inability to drain agents) are unnecessarily constraining.

Complexity is never a virtue. In a system demanding remote control or automated operation--one in which maintenance is hazardous and difficult--complexity is even more troublesome. Examples are suggested in this report to illustrate opportunities for design simplification, particularly in areas that will assist in establishing and maintaining a steady flow of materials.

Recommendation: Instead of waiting for unspecified new technology to be developed, the Army should take every opportunity to improve and simplify the existing technology and processes as the program to dispose of chemical weapons progresses.

Instrumentation Needs

While accumulation techniques such as bubblers permit measurement of time-averaged agent concentrations, no satisfactory techniques have yet been demonstrated for monitoring real-time, low-level concentrations of VX in either ambient air or in stack emissions. In part, this is because of the tendency of VX to adsorb on any surface that it contacts, including instrumentation tubing. However, recent tests by the Army indicate that the problem can be solved.

Recommendation: An accelerated program should be undertaken to develop instrument systems capable of warning plant operators long before agent concentrations reach hazardous levels. These might include instruments whose critical parts operate at temperatures in excess of the boiling point for VX (298^{o}C).

Possible Use of Facilities after Agent Disposal

The Department of Defense generates a substantial quantity of industrial and hazardous waste that needs to be disposed of in an environmentally acceptable manner. It might be possible to reduce substantially the life-cycle costs of the chemical agent disposal systems if their incinerators could be subsequently used to dispose of other wastes.

Recommendation: The Army should explore the possibility of using facilities designed to dispose of chemical warfare agents to also dispose of Department of Defense wastes and perhaps for wastes and hazardous materials from other sources. This exploration should precede final facility design in order to accommodate design features that might economically and safely facilitate such future use.

SYSTEM SAFETY

Need for an Integrated System-Safety Program

Safety has clearly been an important consideration in the Army's programs to dispose of chemical munitions. Soon, however, the Army will be shifting from the experimental operation of a pilot plant by a seasoned crew to "production facilities" with all new personnel. Before this change occurs, there is a need to improve the planning, management, and documentation of the Army's system-safety program. This conclusion is further supported by the following additional findings:

- The system-safety analysis program has relied primarily on inductive techniques. These "bottom-up" approaches seek to determine the consequences of a given failure mode for a specific component. Only preliminary, incomplete deductive analyses have been conducted. These "top-down" approaches identify undesirable end events and seek to determine how they might be caused (see Appendix G).
- The failure mode and effects analysis conducted on CAMDS was less complete and conclusive than would be desired for a new "production" facility.
- The JACADS system-safety analysis is an improvement over that for CAMDS, but still does not include all the tasks identified

in Table 14; for example, no operating and support hazard analysis was performed.

Recommendation: A comprehensive system-safety program should be initiated based on MIL-STD-882B, Army Regulation 386-16, DARCOM Regulation 385-23, and the management oversight and risk tree (MORT). The program should use CAMDS as a test-bed for examining and selecting effective analytic techniques to ensure safety. Additionally, an expanded JACADS safety program should be developed that incorporates system-safety analysis in a timely manner and includes a specific analysis of hazards associated with robots. Likewise, the expanded safety program should be used in designing the final construction details, wherever necessary. Computerized fault tree analysis should be performed for some undesirable end events.

Organization and Responsibilities

Safety personnel are not assigned and organized to conduct an integrated safety program. This conclusion is based on the following findings:

- No single organization is responsible only for the safety of chemical weapons disposal facilities and dedicated to managing a comprehensive system safety program.
- A comprehensive and up-to-date hazard oversight and tracking system does not exist.
- Analyses have not been maintained on a dynamic, continuous basis.

Recommendation: An adequately staffed organization of system-safety engineers, human-factors engineers, and other safety-related specialists should be assembled to focus exclusively on the program to dispose of chemical munitions as a means to ensure a continuous, coherent safety program throughout the life of the system. This organization should be responsible for:

- Immediately installing an information system to track and correct identified hazards.
- Ensuring that quantitative analytic techniques are used to identify single-, dual-, and multiple-fault paths, where appropriate. Additionally, these techniques should be cross checked--inductive against deductive and vice versa--and be appropriately applied throughout the life cycle of the system.
- Conducting a timely safety and human-factors review of all engineering and management changes, designs, operations, and procedures.

Additionally, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) should establish an independent safety audit team, consisting of civilian and military experts in the various system-safety disciplines related to the safe disposal of chemical munitions. This team should review the safety program and audit the facilities on an on-going basis. This team should have the authority to make unannounced visits and to investigate accidents. It should operate separately from, and in addition to, the existing Surety Office inspections and field safety activities. Nevertheless, cooperation among all of them is essential.

Technology Information

Some information that could affect decisions and operations appears to be incomplete, incorrect, or out of date. For example, Army Regulation 385-28 on the safe disposal of BZ was last updated in 1969.

Recommendation: Information sources that are important to planning and operating facilities to dispose of chemical munitions, should be reviewed and updated, if necessary.

Transportation Safety

The hazards, risks, and costs of transporting chemical munitions and agents are not well known. Consider the following findings:

- Army transportation considerations are dominated by the very high costs experienced in earlier air transport operations.
- Contractor studies are contradictory--showing truck transport to be the least costly mode in one study and rail transport in another.
- Hazard and risk analyses have not been done with sufficient rigor either for transport or on-site disposal to permit a meaningful comparison between the options.

The Army is considering, but is not now planning, off-depot transportation of these agents. The panel does not recommend such transport. Nor does the panel have a quantitative basis to dismiss the option--transportation does offer some attractive advantages. Neighbors of any current storage depot can be expected to ask that the materials be transported elsewhere for disposal. Similarly, neighbors of proposed alternative disposal sites and all persons along transport routes can be expected to object.

Nevertheless, while the panel has not been able to study transportation in detail, it believes that transporting munitions such as M55 rockets to centralized disposal depots would not be safer than on-site disposal. Of all chemical munitions, the M55 rocket is the least likely candidate for safe and economical transport.

Recommendation: M55 rockets should be destroyed where they are located for the following reasons:

- They exhibit the highest proportion of leakers.
- They are the weakest agent-containment vessel.
- They contain the highest proportion of explosives (and propellant) relative to total weight.
- They are fuzed.
- Detonations or fires are known to provide enough heat to initiate further detonations.
- Once ignited they can move under their own propulsive power.

For chemical weapons and agents remaining after the expedited programs have been completed, disposal at properly designed and appropriately scaled on-site facilities will probably cost less than transportation and disposal at large, central facilities. This should be investigated further. Additionally, the panel is concerned that delay in the face of opposing public pressures can only lead to increased cost and decreased safety.

Recommendation: The Army should undertake an expedited depot-by-depot assessment of the risks and costs of transporting munitions for disposal at consolidation sites. These results can then be compared with on-depot disposal options. Such a study should examine the potential for carrying stocks from Aberdeen and Umatilla by U.S. Navy vessels to Johnston Atoll for disposal. Transporting stocks from Tooele to Umatilla for subsequent shipment to Johnston Atoll is another option to be considered.

HUMAN FACTORS

Need to Extend Human Factors Activities

Some human engineering studies concerned with the human-machine interface have been performed for CAMDS and JACADS. They are called for in the procurement specification for the Advanced Demil Concept Development. The panel, however, has received no explicit information to indicate whether these efforts actually influenced the design at CAMDS and JACADS.

Recommendation: Before designs are completed and construction begins for JACADS, the Army should conduct a detailed review of the CAMDS operation to identify those human factors that need to be taken into account in future designs. These considerations should be exploited to the maximum extent possible to minimize design-induced errors or performance degradation at JACADS and all other chemical weapons disposal programs.

Training

Operating and maintenance personnel might not be trained to cope with some abnormal events because (1) the current training program at CAMDS is largely based on "over-the-shoulder" demonstration and practice of normal operations, and (2) the development of formalized training plans for JACADS and future disposal operations has lagged.

Recommendation: USATHAMA should prepare an instructional system development methodology tailored to the chemical weapons disposal program. That methodology should be used to:

- Improve and document training at CAMDS.
- Develop training plans for JACADS.
- Develop training plans for the expedited M55 and BZ disposal programs, and for advanced technology projects.

Part IV
Appendixes

A

Toxicology of Chemical Agents

There are four major agents in the stockpile that are candidates for disposal. These are mustard gas or H, $C_4H_8Cl_2S$; sarin or GB, $C_4H_{10}FO_2P$; VX, $C_{11}H_{26}NO_2PS$; and BZ, 3-quinuclidinyl benzilate.

In addition to these the Army has small laboratory quantities of other toxic agents, mainly a legacy from World War I. Some, along with their toxic classification, are listed here, but they are not in the current Army stockpile and will not be further discussed in detail. They are the vesicant (chemicals that induce skin blistering) lewisite ($C_2H_2AsCl_3$) and the pulmonary irritants chlorine (Cl_2) and phosgene ($COCl_2$). The physical and toxic properties of the four major agents are summarized in Tables 14 and 15 and discussed in more detail in the following pages.

MUSTARD GAS

Physical, Chemical, and Toxic Properties

Mustard gas is termed agent H by the U.S. Army and comes in three varieties that differ mainly in purity. H is the crude agent made by the Levinstein process (Mann and Pope, 1922). Distillation of the crude material yields HD. A mixture of HD (60 percent) with a similar compound T ($ClC_2H_4SC_2H_4)_2O$) is termed HT (Department of the Army, 1975). HT has the advantage of a lower melting point than pure HD, which freezes at 15°C and therefore cannot be poured at low ambient temperature.

Mustard gas belongs to a family of toxicants, the N-, S-, and O-mustards. Mustard is a colorless, oily liquid with a garlic odor. It quickly numbs the olfactory neurons, after which the odor is no longer detected. Although the boiling point of this "gas" is relatively high (225°C), it has a significant vapor pressure at ambient temperatures and even in the solid state at 0°C the vapor pressure is 0.025 mm of Hg (Merck, 1976). This is 28 percent of the

TABLE 14 Chemical and Physical Properties of Agents[a]

Agent	Chemical Formula	Molecule weight (daltons)	Boiling Point (°C)	Melting Point (°C)	Vapor Pressure at 20°C (mm Hg)
H	$C_4H_8Cl_2S$	175	225	5 to 14	0.059
HD	$C_4H_8Cl_2S$	159	217	14	0.072
HT	[b]	(HD = 159)[b]	228	0	0.079
		(T = 263)[b]			
GB	$C_4H_{10}FO_2P$	140	158	-56	2.2 (25°C)
VX	$C_{11}H_{26}NO_2PS$	267	300	-51	0.00066
BZ	$C_{21}H_{23}NO_3$	337	[c]	167	1.43×10^{-10}

[a] H, HD, HT, GB and VX data (U.S. Army, 1975).
BZ data (Defense Technical Information Center, 1977).

[b] HT is a mixture of 60% H and 40% T, $C_8H_{16}Cl_2OS_2$.
T is known as bis (2(2-Chloroethylthio)ethyl)ether.

[c] BZ decomposes before boiling.

TABLE 15 Toxic Properties of Agents

Agent	LD_{50} (mg/kg)	LCt_{50} (mg-min/m^3)	TLV-TWA (mg/m^3)
H		1500[a]	0.003[a]
GB	1.015[b]	100[b]	0.0001[b]
VX	0.0075[c]	35[c]	0.00001[c]
BZ	0.5-3.0[d]		

[a] The LCt_{50} is based on 6 hr exposure of rats to H vapor (Edgewood Arsenal, 1975).

[b] LD_{50} is average of several species after intravenous administration. LCt_{50} is estimated in man for ≤ 2 minute exposure (Edgewood Arsenal, 1971).

[c] LD_{50} and LCt_{50} are estimated in humans (Edgewood Arsenal, 1970).

vapor pressure at 30°C. Mustard gas is virtually insoluble in water, but, because of its high lipid solubility, it rapidly penetrates the skin. Mustard is considered "persistent." One report indicates prolonged contamination of French soil after use of mustard during World War I (Case and Lea, 1935). However, another report indicates a half-life of only 5 minutes in water at 37°C (Bereblum, 1935).

Although inhalation of mustard gas produces pulmonary edema, it is usually classified as a vesicant. Perhaps of greater importance because it is often overlooked, mustard is apparently a potent carcinogen in man and animals (IARC, 1975). In one study, inhalation of mustard gas for only 15 minutes produced lung tumors in mice during an 11-month observation period (Heaston and Levillain, 1953).

Current Exposure Limits for Mustard Gas

The Army currently uses four air concentration levels as worker exposure limits: a short-term limit of 0.4 mg/m^3; a single 3 hour limit of 0.01 mg/m^3; a single 8 hour limit of 0.005 mg/m^3; and an 8 hour, 5 day limit of 0.003 mg/m^3. In addition, limits for exposure to the general population are 0.01 mg/m^3 (ceiling), 0.00033 mg/m^3 (3 hours), 0.00017 mg/m^3 (8 hours), 0.0001 mg/m^3 (indefinite). The origin of these limits is from consideration of studies discussed in Edgewood Arsenal Special Publication 740-30 (Edgewood Arsenal, 1975).

GB OR SARIN

Physical, Chemical, and Toxic Properties

Sarin, also known as GB, is the most volatile of the nerve agents in the U.S. stockpile and, for this reason, is mainly an inhalation hazard. Even so, the 158°C boiling point of this nerve "gas" indicates that it will not dissipate immediately if spilled. GB is readily hydrolyzed by either acid or base to relatively non-toxic products. The hydrolysis products, hydrofluoric acid and isopropyl methylphosphonic acid, both can readily attack metal, which may explain degradation of some weapons. GB is miscible with water, but under neutral conditions (pH 7) the half-life for hydrolysis is several days (Larsson, 1957).

GB is an extremely active inhibitor of cholinesterase. By forcing the build-up of acetylcholine at the synapsis of cholinergic nerve fibers, GB causes victims to experience pinpoint pupils (miosis), increased salivation, abnormal tearing of the eyes, urination, diarrhea, convulsions, respiratory collapse, and death. The LCt_{50} of GB is 100 mg-min/m^3. Early treatment with oxime derivatives, such as pralidoximine, can accelerate regeneration of cholinesterase, especially in the peripheral nervous system (O'Leary et al., 1961). Treatment with atropine, an inhibitor of acetylcholine release, can also mitigate the toxicity of GB.

Victims surviving the acute cholinergic effects of GB may suffer delayed neuropathy syndrome characterized by degeneration of peripheral nerves and permanent paralysis (Gordon et al., 1983). In addition, like similar compounds (Wilson and Fraser, 1977), GB may cause abnormal fetal development. For this reason, pregnant women are restricted from areas containing the agent.

Current Exposure Limits for GB

The U.S. Army has seven exposure limits for GB. Four are for unmasked workers. They are: single exposure, 1 hour, 0.001 mg/m^3; single exposure, 8 hours, 0.0003 mg/m^3; 5 days, 8 hours per day, 0.0001 mg/m^3; and 20 minute peak limits, 0.025 mg/m^3. Three exposure limits are used for the general population: single exposure, 1 hour, 0.0001 mg/m^3; single exposure, 1 day, 0.000003 mg/m^3; and 20-minute peak limits, 0.025 mg/m^3. The analytic basis for the current exposure limits is given in Edgewood Arsenal Special Publication 100-98 (Edgewood Arsenal, 1971).

VX

Physical, Chemical, and Toxic Properties

VX is a clear to straw-colored, oily liquid. It has a high boiling point (300°C) and evaporates more slowly than GB. It is both an inhalation and a skin contact hazard. Despite its low vapor pressure (0.00066 mm of HG at 20°C), a person would have to breathe air saturated with VX vapor for only a few minutes to attain the LCt_{50} (35 mg-min/m^3).

VX is more toxic than GB by all common routes of administration. It is about twice as toxic by inhalation and 10 times as toxic by oral administration. It is 170 times as toxic as GB by percutaneous administration in man, and 7000 times as toxic by subcutaneous administration in rats. The immediate, acute toxic effects of VX are like those of GB, and its mode of action is similar. Because VX does not contain a phosphorus-fluorine bond, as does GB, it is unlikely to produce delayed neuropathies in patients recovered from acute VX poisoning (Gordon, et al., 1983).

Current Exposure Limits for VX

The U.S. Army has six exposure limits for VX. Four are for workers. They are: single, one-hour exposure, 0.00005 mg/m^3; single, 8 hour exposure, 0.00002 mg/m^3; 5 days, 8 hours per day, 0.00001 mg/m^3; and maximum limit, 0.2 mg/m^3. There are two VX exposure limits for the general public: single, one-hour exposure, 0.00001 mg/m^3; and 72 hours continuous exposure, 0.0000003 mg/m^3. The analytic basis for the current VX exposure limits is given in Edgewood Arsenal Special Publication 1100-10 (Edgewood Arsenal, 1971) and "Information Briefing on Nerve Agent VX: Annex A: Properties of VX" (Tooele Army Depot, SDSTE-ADS, 9 June 1980).

BZ

Physical, Chemical, and Toxic Properties

BZ (3-quinuclidinyl benzilate) is a muscarinic, cholinergic, blocking agent similar to atropine or scopalamine. It has relatively low toxicity as a lethal agent, but is a potent psychomimetic. At doses of 1-5 mg/kg, it produces hallucinations, confusion, delirium, amnesia, rapid heartbeat, dilated pupils, ataxia, and weakness. Symptoms may last a week, usually followed by a complete recovery. Anticholinesterase drugs, such as physostigmine, are effective antidotes. BZ is soluble in acid and has a half-life in solution of several years.

An air concentration of BZ aerosol of 0.02 mg/m^3 is considered safe for ten 10-minute exposures per week. A provisional maximum permissible concentration (mpc) in drinking water of 0.004 mg/l has been promulgated by the Defense Technical Information Center, in Technical Report 7710 (Defense Technical Information Center, 1977).

Current Exposures Limits of BZ

The panel did not have available any documents containing either suggested limits or the basis for estimating such limits, although the existence of such documents has been affirmed by personnel at Edgewood Arsenal.

B

Stockpile Assessment Panel Site Visits

The Stockpile Assessment Panel or a subpanel of its members visited all eight Army depots in the continental United States where chemical agents and munitions are stored. The visits took place between November 1983 and March 1984. The panel's report on each depot follows.

SITE VISIT TO EDGEWOOD AREA, ABERDEEN PROVING GROUND ARSENAL, MARYLAND MARCH 8, 1984

The Edgewood Area of the Aberdeen Arsenal is located 15 miles northeast of Baltimore, Maryland, on the Gunpowder Peninsula. The peninsula extends into the Chesapeake Bay between the mouths of the Bush and Gunpowder rivers. The area encompasses approximately 65 square miles. The installation has a population of approximately 5,000 military and civilians. It is not immediately contiguous to densely populated areas, although several small communities of 3,000-9,000 in population as well as scattered farms lie within 3 miles of the Edgewood Area.

Small working quantities of chemical materials are or may be stored throughout the installation. To date only one possible leaker has been detected at Aberdeen. The major sensitive areas are the chemical agent storage yard and the chemical storage and transfer facility. The former stores 1-ton containers of mustard in the open.

The chemical storage and transfer facility is a specially designed building for chemical agents used in or returned from the research laboratories at Edgewood. It houses several tons of chemical agent. It is moved in small amounts (usually less than 25 pounds) to and from laboratory work areas.

Significant Points

Bulk mustard was produced by the Edgewood Arsenal in the 1950s and stored in the chemical agent storage yard. The stocks are in condition code A (ready for issue without qualification). A surveillance report dated December 21, 1983, stated that "there were no leakers, that all containers had been repainted and that no evidence of rust existed." A recent sample analysis disclosed that the contents from one of the containers was 77 percent pure. (the Army has indicated that the average current purity of all mustard bulk lots sampled was 76.8 percent.) These indicate that there is minimum deterioration with age.

Discussions with the chemical surety officer, security officer, and personnel from safety and storage gave every indication that the safety and security management of the Edgewood chemical stocks complied with the appropriate Army and DARCOM regulations. A December 1983 Army inspection showed no failing deficiencies in the operations.

Guards are in place at Aberdeen 24 hours everyday, and the chemical storage and transfer facility has an intrusion detection system. Documented, 1-hour patrol checks are conducted, and security guard penetration exercises are performed regularly. First-entry monitoring and visual inspection are performed daily as appropriate. Access to exclusion areas complies with the appropriate Army regulations (AR 50-6 and AR 50-6-1). There is no movement of mustard containers outside the yard, and they are stored with antiaerial devices in place. All movements of research agents appear to be conducted in accordance with applicable security and safety directives and regulations.

Discussions with Aberdeen personnel during a visit to that facility indicated a knowledge of safety and security requirements, and a demonstration of the great effort expended in handling, packing, and transporting agents to laboratories. The same concern was apparent for the handling of toxic waste materials and the small disposal effort.

The Edgewood Area, which began chemical agent operations in 1917 as a fill plant and testing facility, contains what is referred to as "unwanted chemical surety material." A cleanup plan has been adopted to sweep the surface of the area prior to the arrival of the Drill and Transfer System (DATS) in 1985. The unwanted material is currently placed in special ammunition igloos in a separate exclusion area and secured in accordance with current regulations.

In summary, it appears that a sound chemical safety and security program exists and is being used. Current actions seem to be adequate for normal industrial operations.

Comments and Suggestions

From a security standpoint, a penetration by land of either of the two main storage exclusion areas by an outside source seems unlikely. Constant surveillance and security force availability make the act of ootaining mustard agent from Edgewood very difficult. More likely is internal penetration or mishandling of an agent, especially when considering the small amounts (often a liter or less) handled by the R&D program and the laboratories.

If Edgewood's past record is any indication, however, there is little safety risk in the storage and handling of agents. Further, containment plans apparently would preclude an accident or incident resulting from current operations.

Danger to on- and off-post personnel would appear to be almost nonexistent (except from a massive explosion and fire). Prevailing winds are from the Northeast 70 percent of the time, which would carry any released agent over the water and away from populated areas. South winds up the bay are rare, but the local analysis indicates no agent movement off the post in any event; however, a maximum credible event involving a large release was not identified.

Little environmental risk is evident except possibly from a massive explosion and fire. Even then the scattered mustard could probably be contained. The segregation, location, and small amounts of VX and GB also make serious environmental contamination by these chemicals unlikely.

Edgewood's chemical personnel seem competent and well aware of their responsibilities. No real problems in deterioration of product or in its protection, use, or storage were evident. However, Edgewood officials have not determined just what the maximum credible event should be for the laboratories. At present, it appears to be an industrial-type accident or incident at the chemical storage yard, such as a sheared valve on a one-ton container spilling 25 pounds of mustard on the ground. The chemical storage and transfer facility could experience a small spill that is contained while the laboratory could have a gas explosion that causes the release of a small amount of GB into the room.

While all of the above could happen, the question remains of whether plans for a maximum credible event are complete enough considering the potential terrorist threat.

SITE VISIT TO LEXINGTON-BLUE GRASS DEPOT, KENTUCKY NOVEMBER 29, 1983

The Blue Grass Depot is located about 50 miles south of Lexington, Kentucky. The site itself is in a rural area, but less than 3 miles away is the city of Richmond, with a population of 34,000 (including approximately 12,000 students normally attending Eastern Kentucky University). Smaller towns are located even closer to the depot (Reeds Crossing is slightly more than 1 mile from the storage area), and public roads run along its boundary.

The facility, which has an area of about 5 square miles, stores mustard gas in 155-mm projectiles; VX in 155-mm and 8-inch projectiles, and in M55 rockets; and GB in 8-inch projectiles and M55 rockets. All munitions are stored in the chemical exclusion area in steel reinforced, concrete igloos. No munitions are moved out of the chemical exclusion area and only limited transport occurs within the exclusion area.

The depot has a natural topography that makes it a suitable ammunition storage site. The site averages 900 feet above sea level on an undulating plateau, an open and lightly forested area. The risk from fire and flood seems very low. The concrete igloos should be able to survive most natural and human-generated disasters. The risk from tornados seems very low, too.

Significant Points

The Blue Grass facility appears to be well run, with appropriate concerns for safety. Nevertheless, there seems to be a potential management problem concerning its relationship to the Anniston Army Depot in Alabama, which has command authority over the Blue Grass Depot. The latter's responsibilities unrelated to toxic and chemical weapons and its distance from Lexington make command oversight difficult, particularly when the military component of both facilities is limited.

The Blue Grass facility stores M55 rockets, which are probably the most dangerous chemical munitions in terms of their threat to depot personnel and to off-base civilians.

Chemical munitions stored at the Blue Grass Depot date from 1954. There is little information available at the storage site concerning the rate of corrosion and deterioration.

Blue Grass' security system meets Army regulations. Toxic agents could be released or obtained by force, but a substantial military-type operation would be necessary to penetrate the depot from the outside. The risk to the public seems low.

The Blue Grass facility has a potential problem of incidents and accidents caused by their own workforce. This problem is shared by all storage facilities. The risk to the public is low, but probably greater than the risk from external force.

The risk from natural phenomena is low, but unquantifiable from the information available. The risk from human-generated phenomena, such as aircraft crashes, is similarly low but real. Both these risks require appropriate evaluation.

There may be some risk from earthquakes. The Tate Creek Fault crosses the northwest boundary of the depot and swings in a southeasterly direction. A splinter fault branches from the Tate Creek Fault. However, since there is no way to evaluate this information, the risk of earthquake damage is unknown.

Aircraft fly over the Blue Grass Depot. There is a small airport a few miles to the west, though aircraft using this airport do not fly over the depot. A facility at the southern end of the depot supervises practice runs made by the Air Force's Strategic Air Command

(SAC) bombers, which fly over the depot at low elevation. The concrete igloos may be able to sustain a direct hit by a large aircraft without adverse effect on the chemical munitions, but this question needs to be examined. The igloos are designed to be unaffected by explosions of nearby igloos.

Comments and Suggestions

The Lexington-Blue Grass Depot has a long history as a munitions storage facility. Its physical characteristics minimize adverse effects from natural causes. The facility is well run and cared for by a quality workforce.

Nevertheless, the facility is a poor one for storing chemical munitions. The closeness to population centers and the relatively small size of the depot leave little margin for protection of the public in the event of an accident or incident. The facility's maximum credible event, which includes exposure of off-site populations from M55 rockets, makes the danger even greater. The immediate removal and/or disposal of the M55 rockets should be the highest priority of the chemical disposal program. While other chemical munitions do not present any immediate danger, Lexington-Blue Grass is not a good site for their storage. A maximum credible accident could deliver chemical agents to nearby areas with substantial populations.

SITE VISIT TO NEWPORT ARMY AMMUNITION PLANT
NOVEMBER 30, 1983

The Newport Army Ammunition Plant is a government-owned, contractor-operated facility. The current contractor, Uniroyal, operates the facility with oversight provided by the Army commander and his staff. Newport manufactured the chemical agent VX and chemical munitions from 1960 to 1968. Residual bulk agent is stored in 1-ton containers.

Stocks have been kept since 1976 in a building formerly used as a fill facility. The building was not designed for storing chemical weapons. Temperature and humidity are not controlled. No other ammunition stocks are stored at Newport. The 1-ton containers, similar to those used by the chemical industry to store chlorine, were reconditioned in 1978 and 1979. No leaks have occurred at Newport.

Probability of Accident or Incident During Storage

The chemical agent VX is a relatively nonvolatile liquid. The risk due to a leak in a 1-ton container is, therefore, of a different kind than in the case of a gaseous agent that might be released into the air. The storage building, formerly a munitions fill facility, was designed to include an integral drainage system that could collect and isolate liquids for decontamination. As such, the risk associated with a leak seems low. The 1-ton containers are in static storage, so that the risk associated with their handling or transport on-site also seems low. There are no other munitions or explosives stored on-site; hence, there is no current risk that hazards associated with other munitions may affect the storage of chemical agents.

There is little evidence to suggest that degradation of the 1-ton containers represents a high risk. It is difficult to judge, however, their long-term stability based solely on visual examination of the exterior condition of the containers, particularly since the Newport containers were recently reconditioned. Because the storage building is neither temperature- nor humidity-controlled, water does condense on various occasions. Dissimilar metals are used in the brass valves, and the fittings are inserted into a carbon steel container wall.

It is currently impossible to inspect the containers for inside-out degradation. Further, there seems to be little information available on the chemical stability of the container materials exposed to the agent. It would be helpful to know more about the chemistry (formulation, pH, conductivity, oxygen content, etc.) of the agent.

It seems quite unlikely that the containers could be penetrated as a consequence of natural (tornado, earthquake) or man-made (fire, plane crash, terrorist activity) disasters. It appears, however, that contingency plans are not available to deal with such extreme events. Although the probability of their occurrence may be low, their consequences are so great that attention should be given to such matters, particularly if nerve agent is to be stored at Newport rather than disposed of.

Consequence of Accident/Incident During Storage

Although there are contingency plans for on-site personnel in the event of a chemical accident or incident, the impact of such an event on the surrounding communities seems not to have been studied. One exception is the recent environmental impact assessment done for the construction and operation of a toxic chemical laboratory at Newport. The laboratory analyzes air samples collected during surveillance of the storage facility.

It appears that containment and decontamination of individual leakers may be handled with little risk. No such incidents have occurred at Newport, which provides additional evidence that release of an agent is a low probability. It is difficult, however, to assess the probability of such events in the future with the limited information now available.

It is not clear that Newport could handle a massive chemical incident resulting from terrorist attack or other man-made catastrophe. Given the prospect of continuing storage, it would seem prudent to develop a plan of action. A risk assessment analysis may serve as a useful guide.

Urgency of Disposal

At the moment, there appears to be no urgency for disposing of the VX in 1-ton containers at Newport. There have been no leakers in 15 years of storage and no known evidence of significant stockpile deterioration. On the other hand, the stockpile has not been systematically evaluated on a scale that would allow one to project the rate of deterioration or the potential for concern in the near or long term. It would seem, however, that disposal of agents stored in bulk at Newport would not be difficult.

SITE VISIT TO TOOELE ARMY DEPOT, UTAH
DECEMBER 8, 1983

The Tooele Army Depot is located in a remote area of Utah about 30 miles southwest of Salt Lake City. Established in 1942, it is a major site for storing chemical as well as traditional munitions. More than half of the toxic chemicals and chemical weapons in the United States are stored at Tooele. In addition, the facilities at Umatilla, Oregon, and at Pueblo, Colorado, report to it.

Among the sites visited, Tooele is a model. Its systems for assurance of safety, security, and surety are as satisfactory as can be reasonably achieved within the limits imposed by site location, current technology, budget, and the maximum concerns considered. As a result of population growth in the immediate area, the chemical agents were relocated 17 miles to the south of the main munitions storage.

Public safety is protected primarily by the storage system, in which chemical munitions are kept in separated igloos. The location of igloos is designed to prevent accidents in one igloo propagating to other igloos in the vicinity. The staff appeared carefully and thoroughly prepared to respond to a wide range of anticipated accidental releases and associated injuries. Most were trained locally and have worked at Tooele for many years. They rehearse frequently and are subjected to surprise inspections. Further, access to the igloos is guarded by a security system that should certainly protect against all unauthorized entries, save those involving a conspiracy among a significant number of staff or by a well-armed and equipped substantial force of intruders.

Surety of the stored munitions does not differ from that at other depots, being based on common knowledge, technology, and experience. Concerns as to the stability of the agents and the integrity of the metal containers are identical to those at the other sites. Tooele houses the CAMDS project that disposes of leakers and obsolete munitions.

Security appeared adequate for the nature and level of activity, as did the systems surrounding the site for detecting possible accidental releases of agents. This involves monitoring the air with standard M-18 kits, M-8 alarms, and bubbler systems. While these are not "state-of-the-art" systems, they appear adequate for the limited monitoring requirements of depot operation, specifically in igloo entry for detecting leakers.

More modern methods are available or are being tested. These include a real-time monitor based on cholinesterase inhibition, the Automatic Continuous Air Monitoring System, and an adaptation of a standard gas chromatograph with flame photometric detection. Newer monitors are in place around the depot's southern borders that detect sulfur and nitrogen oxide and particulates.

Tooele's immediate problem is with the storage of M55 rockets. As reported by the Army, the relatively unlikely accidental ignition of one rocket could lead to the ignition of others in the same igloo. This could start an intense fire that could cause the release of significant quantities of agent. Such a release could endanger those within a radius of 6 miles and even farther under certain meteorological conditions. At risk, in addition to the staff at Tooele, are some 1,000 people scattered among small towns, ranches, and mines at distances ranging from 3 to 7 miles. If a sudden evacuation of the site were necessary at quitting time, there could be a serious traffic jam.

Tooele lacks a specific plan for an effective response to a chemical accident or incident beyond the depot. In contrast to the detailed plans in printed manuals for control of chemicals at Tooele itself, there are no guidelines for chemicals that escape outside the immediate confines of the depot. This is typical of most facilities.

Considering that the Tooele Depot was originally located in a relatively remote geographic area, accessible only by railroad for collection and distribution of explosive munitions, the juxtaposition of a substantial concentration of civilian residents in proximity to substantial amounts of potentially insidious toxins poses an array of problems that have not been addressed.

The town of Tooele, with about 10,000 people, is 18 miles to the north. The largest population center, Salt Lake City, is more than 30 miles away.

Although there is no significant known reason to be concerned about the danger to the public or local staff from current activities at Tooele, it would be advisable to improve the precautionary measures. Despite the precautions taken when igloos are opened, there is a risk at that time. It should be possible to reduce the number of times igloos must be opened by developing sensors that can monitor the air inside.

The development of better detection techniques should be encouraged. At the same time, more knowledge relevant to accidental releases of chemical agents should be sought, particularly more information on wind patterns and their variation.

SITE VISIT TO UMATILLA DEPOT ACTIVITY, OREGON
JANUARY 11-12, 1984

The Umatilla Depot was constructed just prior to World War II and subsequently served as the major supply depot for operations in the Pacific. At present, it stocks standard as well as chemical munitions. The depot, on about 20,000 acres, is located in north-central Oregon about 5.5 miles southwest of the town of Umatilla (population 3,000), 6.25 miles due west of Hermiston (population 10,000), and 33 miles northwest of Pendleton (population 15,000). The Union Pacific Railroad and Interstate 84 both run a short distance to the south, and the Columbia River flows a few miles to the north. The surrounding area is primarily agricultural with large wheat and cattle ranches. A large hog-raising farm is located just across Interstate 84 from the depot. The area has very low rainfall.

The Umatilla Depot Activity, as it is formally called, reports to Tooele. It has the largest store of chemical weapons after Tooele. The chemical munitions are located in a special exclusion area within the depot. Storage of the chemical munitions and control of access to them are very similar to Tooele.

Munitions stored at Umatilla include VX in projectiles (155-mm and 8-in), 115-mm rockets (M55), spray tanks, and mines; and GB in projectiles (155-mm and 8-in), bombs (500- and 750-pound), and 115-mm rockets (M55). Mustard is present only in 1-ton containers. All VX and GB munitions are kept in igloos similar to those at Tooele. The mustard tanks are kept in a covered building within the exclusion area.

Except for the provost marshall, the military staff with the drill and transfer projects, and the medical officer, all depot personnel are government civilian employees. The security staff are all ex-military people. Because of the limited size of the staff, most personnel working with chemical agents also work with conventional munitions.

Significant Points

Umatilla has had 123 leakers since 1962, of which 77 were M55 rockets. Four were found only the week prior to the panel's visit, and, curiously, all were located in the same pallet adjacent to each other. The apparent rise in the numbers of leakers, according to the Umatilla staff, may be the result of the recent improvement in the sensitivity of the detection systems. Rabbits were used until last year; now bubblers based on an enzyme assay are used to detect chemical leaks. A detection system is under development that will collect chemicals by passing air through a column, with subsequent analysis in a gas chromatograph.

The rate of industrial accidents at Umatilla is low, possibly because of the slow and careful procedures used. The low accident rate perhaps reflects the fact that chemical area is estimated by its staff to account for about 30 percent of the work on the base. Also, the staff receives extensive safety training.

As at other depots, the medical staff receives inconsistent and intermittent instruction and training for dealing with chemical casualties. For example, the current medical officer had been at Umatilla for six months before being sent for appropriate training. This appears to be due, in part, to the relatively minor role chemically related problems play in the overall responsibilities of the medical staff. There is scope for increased medical preparedness for dealing with chemical accidents or incidents, and attention should be given to integrating the medical support activities more closely with the chemical surety mission.

An inquiry into the controls used for cholinesterase determinations revealed that all samples--routine and incident collected--are submitted to the pathology department of Fitzsimmons Medical Center in Denver.

The experience of the medical officer in chemical agent procedures and CAIC response led to the development of a course developed at Savanna, Illinois, for Umatilla last August. All identifiable civilian medical and health personnel in the Umatilla area were invited to take the course, and about 40 did. Reactions were very favorable, and periodic repeats of the course were proposed.

Comments and Suggestions

Except for some bubblers near the drill and transfer site, there is no environmental monitoring, either outside the depot nor along its perimeter. If the regular monitoring of igloos were improved, the need for perimeter monitoring would decrease. Currently, only suspect igloos, such as those with rockets, are tested with any regularity. Umatilla staff have recommended a system for sampling the air in an igloo without the need to open the door. Their proposal seems a desirable improvement over the present system.

Umatilla appears to have no problem dealing with small accidents. In the event of a release, two-man teams (of which there are a minimum of five) are assigned to monitor specific spots on the site. They rehearse quarterly and monitor off-site if necessary. If the staff calculations are correct, an industrial-level accident would not seriously affect areas outside the depot. A spill of one-fourth the contents of a 750-pound bomb would have 1 percent lethality at 675 feet, well within the site.

But there would be the possibility of danger for the public outside the site if a major accident occurred. The most likely candidate for such a disaster is the M55 rocket. An explosion in an igloo containing rockets might ignite many of them with the estimated release of 575 pounds of GB, giving 1 percent lethality at about 5 miles, a range that could very well jeopardize Umatilla and Hermiston, plus the several smaller communities near the depot.

Local public safety officials have developed plans for coping with a large release of chemical agent. Still, there could be less than an hour to warn and evacuate a population of 10,000 if casualties were to be avoided. The Umatilla Army Depot normally provides gas masks to the local and state police, but at the time the panel's site visit these masks had all been recalled to the base because of a shortage of masks meeting inspection requirements.

Concern over the ability of local officials to deal with an accident requiring evacuation led the panel to visit Hermiston's Safety Center. Hermiston officials are much more aware and prepared for dealing with a chemical incident than we anticipated. Large portions of their plans for local and regional response to such an event can be considered a model for other communities.

Umatilla's security system is adequate to deal with small numbers of untrained intruders. But it would not be adequate to deal with the admittedly unlikely event of an attack by a trained and well-armed group.

In summary, the panel concludes that there are a number of small problems at Umatilla of the kind described above that could easily be corrected. There is one serious problem, however, with storage of rockets so near to population centers. The panel urges that high priority be given to disposal of these rockets. If the rockets cannot be disposed of quickly at Umatilla, they should be transferred to Tooele, which can dispose of them. The rockets could be flown from Umatilla, which has an airfield capable of handling military transports, to Tooele, over areas of very low population density in eastern Oregon and Nevada and Utah.

SITE VISIT TO CITY OF HERMISTON SAFETY CENTER, OREGON
JANUARY 12, 1984

Hermiston takes considerable pride in its Safety Center, a combination of civil defense, local police, and fire department resources with centralized communication facilities. Based on what the panel had heard at Umatilla, the local agencies were expected to be relatively unprepared for a serious incident threatening the towns of Umatilla and Hermiston. To the contrary, the local officials had given considerable thought as to how they would cope with an emergency requiring rapid evacuation of a large number of people from the two communities.

One panel member met with the Hermiston town manager and civil defense director, the Hermiston fire chief, a police lieutenant, and the Umatilla depot's civilian executive assistant. The local officials seemed well aware of the potential for a serious accident at Umatilla that would require a rapid evacuation of the local population. They have prepared an "emergency operations plan" to deal with such a contingency.

Several years ago, the local public safety officials participated in a simulated emergency situation. In it, an earthquake released toxic chemicals in the same amount as the Army's assumption for an explosion in an igloo of GB-filled M55 rockets. The local officials worked through this exercise in the conference room above the communications switchboard in the Safety Center. A report describing the evaluation of the exercise made it look like a relatively detailed rehearsal for the officials involved.

The mayor and the fire and police officials did not regard evacuating Hermiston in an hour as a particularly difficult task. Using the police, regular and volunteer firemen, and public works employees, they estimated that 50 persons could be sent within 5 minutes to warn the public.

Road egress from the communities is not a problem; there are several wide roads leading out of town away from the Umatilla depot. Wreckers or public works vehicles could quickly remove any stalled cars. The officials felt that the local medical people are prepared for a chemical emergency; many local doctors took the course at the base last year and the local hospital has stocked the nerve agent antidotes atropine and PAM-2 chloride.

There are several problems that might reduce the effectiveness of the emergency response by the local agencies. Most importantly, the gas masks issued to local agencies by the Umitilla depot have been temporarily recalled because of a shortage in masks at the base that meet the current inspection requirements. Additionally, there are 15 rubber suits each with overpressure, self-contained breathing apparatus that could protect firemen, but no other protective gear is currently available off the base for use by local public safety personnel during an emergency.

The ability of the communications center to cope with an extreme emergency situation was questioned, since it is set up for only one operator. In an emergency, the volume of communications traffic might be far too much for a single operator to handle. There is no provision in Hermiston's plan for relaying information to the conference room upstairs other than someone carrying messages back and forth.

Nevertheless, Hermiston has done as good a job of preparing for an accident at the Umatilla depot as any community threatened with potential disasters that could cause large-scale fatalities. The local officials seemed well aware of the magnitude of the threat from a large amount of chemical agents released from the depot. They have carried out a planning exercise to determine how they would cope with an emergency of this nature.

SITE VISIT TO ANNISTON ARMY DEPOT, ANNISTON, ALABAMA JANUARY 24, 1984

The Anniston Army Depot, which totals 15,000 acres of rocky terrain including 42 acres of water, is located in a valley 50 miles east of Birmingham, Alabama, and 110 miles west of Atlanta, Georgia. The population density within a 10-mile radius of the facility is about 190 persons per square mile. Two small municipal airports are located 5 and 8 miles away, and another two still smaller airports within a 10-mile radius of the facility.

Chemical munitions have been stored at the facility since 1964. Except for some leaky GB-filled M55 rockets that were disposed of in 1982, the stockpile has been somewhat stable. The chemicals stored include GB, VX, and mustard. Anniston also stores other munitions and reconstructs tanks.

Since 1981, Anniston has substituted bubblers with gas (and liquid) chromatography for the use of rabbits to monitor chemical leakage. However, bubblers are somewhat inadequate because of the greater sensitivity of humans to these toxic chemicals. Medical monitoring involves a periodic measurement of erythrocyte cholinesterase as well as a detailed physical examination. No incidents of serious exposure to any agents have occurred during the past five years, while the variations from normal cholinesterase levels have been minimal. The procedures used were standard and proven effective in detecting any leaks in the storage facilities.

Risk from Natural Phenomena

The terrain within the Anniston facility consists of heavy, nonporous sedimentary rock with an average thickness of 2,000 feet. Since the terrain has only a few minor faults, the potential for contamination of the groundwater system from minor incidents appears to be minimal. The area has a seismic zone one rating, so that a significant earthquake seems unlikely. Other natural phenomena, such as flooding and severe meteorological events, are not likely to cause serious accident.

One potential problem could arise from the fact that two-thirds of the facility's land is comprised of relatively dense forest, consisting mostly of pine. Since most of the igloos are enclosed by trees, a forest fire might elevate the temperature within the igloos, thereby increasing the likelihood of leakage or an explosion. In recent years, forest fires have occurred on the facility outside the chemical exclusion area.

Risk Factors in Storage

The chemical munitions, which are stored in steel-reinforced concrete igloos with double-locked doors, are located in the chemical exclusion area. Security and surveillance procedures, which follow established guidelines, appear to minimize the risks of internal or external penetration. Most incidents at Anniston have involved leaking containers. From a normal operating standpoint, the safety and security actions in being and planned are adequate to insure protection of personnel and property. Only the most massive accident would cause Anniston's operations to fail--and the site location and available forces in the area do not make this a likely happening.

The Army asked all storage installations in January 1984 to review their hazard zone calculation requirements to assure standardization of maximum credible events as well as their currency and ease of use.

Anniston has a manual outlining the procedures to be observed in the event of a serious chemical incident or accident. In a recent exercise, the control plan was tested by simulating an incident in which a 155-mm rocket containing VX exploded during routine transfer. Although the procedures for decontaminating the agent in the immediate vicinity of the accident are feasible, the problem of decontamination of the surrounding area is considerably greater, particularly if the agent settles in the trees adjacent to the igloos. There was some question, however, whether the staff at Anniston was adequate to handle both an accident at their own facility and one at the Lexington-Blue Grass Depot.

Consideration should be given to establishing a control plan in the event of a terrorist attack involving the chemical exclusion area. Periodic exercises, similar to those used to control a chemical accident or incident, should likewise be initiated to deal with a possible terrorist infiltration. Each facility should review its own security plans and make any necessary modifications.

Each facility would also benefit from having some remote sensors in each igloo containing toxic chemicals. It would be an added safety feature since some igloos are checked internally on a quarterly basis. These monitors could be tied to the central security office just as the intrusion detection system is at present.

The Anniston depot has no particular environmental problems specific to this site. The facility is a storage depot without active work except for monitoring. No harmful residuals or release of agents are expected on land, air, or water.

Vulnerability to External Penetration

Although there have been no incidents involving either internal or external penetration, Anniston is adjacent to two major highways and less than 10 miles away from four small airports. Since the air traffic is very light, the likelihood of an airplane accident within the facility is slight; however, there is little to prevent a sabotage attempt from the air.

Other Risk Factors

At the time of the panel's site visit, Anniston was installing a new surveillance and monitoring system for the chemical munitions stockpile. The plans call for a number of individuals to be in close proximity to the glovebox during the drilling operations. Since drilling into loaded munitions involves a certain risk, the panel recommended that the personnel present be kept to a bare minimum during the drilling operation. It would also be appropriate to initiate a thorough training program prior to beginning the operation. In view of the success of the Army's drill and transfer program, there is a good likelihood that SUPLECAM can be performed with minimal risk.

Recently, an uploading program (GB and VX in 155-mm projectiles) undertaken at Anniston revealed a number of deficiencies. The loaded 155-mm projectiles were suspended from a conveyer belt by means of a simple hook. If a worker accidentally bumped a projectile or secured it improperly, the consequences could be serious. In addition, up to 6 minutes passed before a detector set off an alarm. Although the detector system was adequate for monitoring prior to entry into the working area, it may require modification to reduce the lag time for on-line detection of agents.

Also, the up loading of chemical munitions will add considerably to the risk involved in their subsequent disposal as well as in the loading process itself and in storage.

SITE VISIT TO PINE BLUFF ARSENAL, ARKANSAS JANUARY 25, 1984

The Pine Bluff Arsenal, which was constructed in 1942, is the only producing U.S. Army arsenal. It occupies 22 square miles of relatively flat land in a wooded area about 30 miles southeast of Little Rock. It is bounded by the Arkansas River to the north and east and the Missouri Pacific Railroad on the south and west. The winters are generally mild with only occasional subfreezing periods; the summers are hot and frequently humid.

The nearest city is Pine Bluff, which extends almost to the arsenal on the south. Arsenal personnel and their dependents total about 5,000 persons.

Mustard was shipped to the Pine Bluff Arsenal as bulk agent after World War II. It is stored in 1-ton containers, which are located in an open chemical exclusion area. Unlike other depots, such as Tooele, these containers are deployed in a single row rather than stacked.

All other chemical agents are stored in igloos except for the small amounts of agents undergoing testing, such as phosgene (CK). The latter are stored within the laboratory in a chemical exclusion area. Test quantities (about 1 liter) of GB and VX are actually shipped in from Aberdeen.

M55 rockets containing VX and GB, are kept in their shipping and firing tubes, and are stored 15 to a pallet. The VX rockets were filled at Newport, Indiana, and the GB rockets at the Rocky Mountain Arsenal in Denver, Colorado. Both rocket types were produced between 1961 and 1963, and were shipped shortly thereafter to Pine Bluff. Land mines were also shipped about this same time. The land mines are enclosed within their metal storage containers.

BZ is stored both in bulk containers and in munitions (M43 cluster bombs and M44 cluster generators), where it is blended with pyrotechnic material.

All the mustard containers were cleaned and repainted in 1980 and 1981. The mustard is still usable despite an accumulation of sludge. The panel was told it would take about two years, however, to develop and produce equipment for loading it into field munitions.

All VX- and GB-filled M55 rockets at Pine Bluff are now designated as unserviceable. Thus far, 39 GB rockets have been found to leak--they were disposed of by the drill and transfer team in 1981.

About 1 percent of the VX-filled M23 land mines at Pine Bluff were found to have defective bellville springs. Although this condition does not affect their serviceability, they were nevertheless set aside. All BZ stored at Pine Bluff has surpassed its shelf life and is not considered stable or effective any longer. It is scheduled for destruction when appropriate facilities become available in a year or two.

Possibly the most serious storage accident at Pine Bluff occurred in an igloo containing BZ in 1971. Lightning caused a fire that destroyed most of the igloo's contents. The resulting contaminated material is now stored in other igloos. The circumstances leading to this accident have been eliminated from other igloos by appropriate precautionary measures.

Significant Points

The Pine Bluff Arsenal is the only depot in which all of the Army's toxic chemical agents are stored in substantial quantities. In addition to producing colored smoke grenades, chemicals for screening smokes and incendiaries, and protective gas masks, Pine Bluff performs extensive testing on a continuing basis on all canisters and filters for masks. Pine Bluff also operates a mobile chemical laboratory known as SUPLECAM (Surveillance Program, Lethal and Chemical Agents and Munitions), which samples and tests chemical agents at other storage depots.

Pine Bluff also has primary responsibility for the Drill and Transfer System, which disposes of leaking munitions at other storage facilities by separating the chemical agent from the explosive. The chemical agent is transferred to a bulk container for storage in a designated igloo and the explosives are destroyed by detonation.

Pine Bluff will also have a facility for destroying BZ and another facility for producing difluoro binary component by 1986.

Because of the breadth of responsibility for manufacturing and testing a variety of chemical agents, Pine Bluff Arsenal probably has the most experienced personnel for chemical weapons in the U.S. Army.

Comments and Suggestions

Pine Bluff's security and surety operations appear to be good and comparable to Tooele. Both these installations, however, are susceptible to individuals cutting through the perimeter fence and to suicidal air attack, particularly since the air spaces over the depots are not restricted. Although there is a double fence around the exclusion area, the exit still has only a single fence, making forced entry by a fast-moving vehicle possible.

Because of the heavily wooded pine forest around the Pine Bluff depot, there is some concern that a fire could generate sufficient heat to cause the storage containers and munitions to rupture, which, in turn, might release large quantities of chemical agent into the air.

There is also a remote possibility for theft of a chemical agent in the testing laboratory. Each agent is carefully weighed and logged in before it is transferred to a container or "generator" in a constant temperature bath. Similarly, all quantities of agent removed from the bath for testing are carefully monitored. Still, the amount remaining in the bath at any particular time is not measured directly because of the potential hazard of transferring it from the bath to the weighing container and back.

The igloos at Pine Bluff, like those at all other depots, are continuously monitored only when they are to be inspected. Consequently, since there could be a delay--amounting to a matter of months--in discovering a leaking agent, continuous monitoring is advisable.

SITE VISIT TO PUEBLO ARMY DEPOT ACTIVITY, COLORADO FEBRUARY 15, 1984

The Pueblo Depot lies on rolling prairie land just north of the Arkansas River and 14 miles east of the city of Pueblo, Colorado. Established in 1941, the depot now comprises about 38 square miles. There are several population centers nearby. The largest is Pueblo with more than 100,000 people. Four other towns within a 22-mile radius have populations of 1,000 to 8,000, while two others have less than 1,000.

The Pueblo area is well served by road, rail, and air transportation. The depot is linked to Pueblo by U.S. 50, a 4-lane expressway, which also passes the airport. The airport can accommodate jumbo jets, such as the Boeing 747 and the C-5, as well as other commercial and civil aircraft. Three major rail lines pass just south of the depot, which is connected to these lines by a spur.

The depot lies on an erosional remnant of an extensive alluvial terrace. These deposits are underlaid by shale, which extends downward to 2,000 feet. Southeastern Colorado is located in a seismic risk zone, one where earthquake damage would be expected to be minor. An earthquake, which measured 4.0 on the Richter scale, occurred near Pueblo in 1967. No known faults underlie the depot itself.

Elevation ranges from 4,814 feet in the northwestern part of the depot to 4,474 near the southeastern boundary. There are no natural or perennial streams within the depot and surface waters flow only after rainfall or snowmelt. The climate is semiarid with low humidity (41 percent average), abundant sunshine (74 percent average), and low precipitation (11.5 inches annual average). Very strong winds are most common in late winter and early spring, and usually blow from the North and West.

At the present time, the Pueblo depot stores, disposes of, and renovates ammunition. It also stores munitions and maintains certain equipment and components, such as the Pershing missile ammunition.

Pueblo has 770 government employees, including about 270 in the chemical personnel reliability program. There are also five military personnel at the depot.

The chemical weapons stored at Pueblo include 4.2-inch mortar rounds, and 105-mm and 155-mm artillery projectiles, all containing mustard. No bulk stores are held at Pueblo. These munitions are stored in about 100 igloos in the chemical exclusion area in the northeastern corner of the depot. All were manufactured at the Rocky Mountain Arsenal in the 1950s, except for some of the 4.2-inch mortar rounds, which came from the Redstone Arsenal and date from 1953.

Currently, 46 percent of the 4.2-inch mortars are serviceable (Code A). No artillery projectiles are in Code A condition. Ninety-two percent of the 105-mm shells are Code G (missing a component) and 88 percent of the 155-mm shells are awaiting arrival of the Drill and Transfer System to be disposed of. The principal leakage problem seems to be seepage around the fuze well.

Pueblo follows the procedures outlined in the relevant Army regulations for conducting stockpile inspections and other aspects of chemical surety. They are very similar to those at Tooele, to which Pueblo is administratively responsible. For example, Pueblo has recently begun using bubbler units to detect low concentrations of chemical agent in the air. Pueblo also follows procedures for entering igloos and monitoring work areas in a similar fashion to that at Tooele.

No chemical munitions have been moved from Pueblo for 20 years. The depot has not experienced any accident or incident involving the transport of chemical munitions. However, in 1983 one worker received a mustard burn on the thumb while attempting to plug a leaker.

Significant Points

There are two special features of chemical munitions storage at Pueblo. First, mustard is the only chemical agent kept at Pueblo. It is stored exclusively in projectiles. This significantly limits the severity of the maximum credible event and seems to limit the impact of this event to the confines of the depot itself.

Pueblo's second important feature is the size and layout of the exclusion area. Located on a flat desert terrain, it is laid out in a rough square about 6 miles on a side. A hardened tower is located at the entrance to the area and affords an excellent view of the entire block. This makes surveillance easier and reduces the chances of unauthorized entry.

Comments and Suggestions

The Pueblo depot is competently managed to conform with relevant Army regulations and procedures. Initially, the panel was concerned that the depot was overly dependent on nearby Fort Carson for such things as security and medical support in case of emergencies. In view of the proximity of Fort Carson, however, and further information regarding the speed of response and degree of planning already demonstrated, this concern was allayed.

Several concerns that originally surfaced at other depots reemerged at Pueblo. For example, the medical personnel at several depots are not trained for dealing with toxic chemical casualties until they have been at the depot for 2 to 6 months. This was the case at Pueblo. It may be due, in part, to the lack of emphasis placed on chemical injuries by the Army's Health Services Command at military hospitals outside of storage facilities.

Taking into account the local geography, the nature and storage conditions of the stockpile, and the practices, procedures, and competency of the command, the panel felt there to be relatively modest risks from maintaining the stockpile at Pueblo in its present state. It seems clear, however, that circumstances may require markedly increased and expensive security measures at all storage depots for chemical weapons. If the Army regards substantial portions of the mustard to be obsolete, the time might not be appropriate for making major improvements in security arrangements at Pueblo. An alternative would be to consolidate stocks, thereby minimizing security costs.

C

Stockpile Assessment Panel Questionnaire

NATIONAL RESEARCH COUNCIL

COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS

2101 Constitution Avenue Washington, D C 20418

BOARD ON ARMY SCIENCE AND TECHNOLOGY

October 28, 1983

COMMITTEE ON DEMILITARIZING CHEMICAL MUNITIONS AND AGENTS

STOCKPILE ASSESSMENT PANEL

SITE QUESTIONS

The Stockpile Assessment Panel of the Demilitarization Committee has developed the following questions to be reviewed with the appropriate staff at each facility. A short, concise written response is requested.

1. For chemical agents and bulk munitions stockpiles:

   a. What is the basis for determining the condition (obsolete or deteriorating) of stocks?

   b. What is the method and schedule for surveillance?

   c. What are the security procedures?

2. What is the history of storage of chemical agents at the facility?

3. Where and when were the stockpiles manufactured?

4. What is the policy for personnel associated with chemical agents? including:

   a. number, education, rotation;

   b. military/civilian/contractor status;

   c. extent of security clearance at facility;

   d. authorized vs. actual staff level;

   e. qualifications of commander and other management.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

5. What is the procedure and frequency of transporting munitions and bulk agents on/off site? including:

a. incident/accident history during the last two years;

b. security during each move;

c. availability of emergency medical, firefighter, etc. personnel.

6. Present a short public affairs history for the site/facility including all local/state/regional concerns or problems and a command brochure or other public literature.

7. Present a summary of the operating budget requested, authorized, and appropriated in direct support of the chemical munitions program and operations for each site for FY 82-85.

8. What contingency plans for an incident/accident have been developed? including:

a. for on-site personnel;

b. availability of off-site assistance;

c. impact on the surrounding community.

9. What are the applicable local/state laws relating to chemical storage under which the facility must operate?

10. What is the proximity of non-chemical ammunition stocks stored at the facility? What hazards or procedures associated with them may affect the safety of the chemical munitions and bulk agents?

11. What periodic reports or special studies or inspections of the stocks have been completed during the last two years (including reviews by the Army, DOD, GAO, other)? Provide copies.

12. What are the detailed operating procedures for handling leakers? including:

a. disposition;

b. monitoring methodology;

c. statistical analysis of leakers by type, lot, age, etc..

13. Describe the present medical monitoring program for workers potentially exposed to agent and a history of the change in this procedure during the last five years.

14. Describe the present environmental monitoring program and a history of the change in this program during the last five years.

15. Provide a map and aerial photograph of the site/facility and information concerning the surrounding region including:

a. location, density of population;

b. transportation routes via air, road, water;

c. geophysical, climatological, seismic data;

d. industrial facilities and operations; and

e. land use petterns (agriculture, grazing).

16. If an accident involving chemical munitions were to occur:

a. What population groups, on/off the facility, would be the primary target for protection?

b. What dose response and exposure assessment will be used?

c. How would calculations of wind dispersion or water seepage be determined?

d What are the biological/chemical and statistical uncertainties in estimating the impact?

D

Typical Response to Questionnaire

The Stockpile Assessment Panel of the Demilitarization Committee has developed the following questions to be reviewed with the appropriate staff at each facility. A short, concise written response is requested.

1. For chemical agents and bulk munitions stockpiles:

a. What is the basis for determining the condition (obsolete or deteriorating) of stocks?

PBS does not determine obsolescence, however, based upon inspection criteria of SB 742-1 Quality Assurance Specialist (Ammunition Surveillance) (QASAS) assigned to Pine Bluff Arsenal make determinations on condition of munitions/containers in consideration of deterioration factors detected during periodic/cyclical surveillance.

b. What is the method and schedule for surveillance?

(1) Method: BZ Munitions and Bulk Agent, HT/HD Bulk Agent (Ton Containers), VX M23 Land Mines and VX M55 Rockets, and containers of RDT&E agents are subjected to cyclical visual inspection; GB M55 rockets are cyclically air tested utilizing detection equipment.

(2) Schedule: All chemical munitions and agents are inspected on a cyclical basis throughout the year using lot sampling criteria prescribed by SB 742-1. It should be noted that storage igloos are entered from 5-7 times annually to accomplish surveillance operations, magazine inspections, or periodic security checks.

c. What are the security procedures?

Each storage structure is secured with two high security locks. A security guard must obtain a separate key for one lock which is assigned to Security personnel; an individual from the operational element must obtain a separate key for the second lock which is under control of the operational element--this allows enforcement of the two-man rule which must be followed in opening the structure. In addition, specific igloo opening and closing procedures must be followed since the structures are protected by an Intrusion Detection System. The Chemical Exclusion Area within the chemical laboratory facility requires two individuals--a security guard and an individual from the operating element--to open the outer door of the laboratory, and two operating personnel to open each of the dual locks which secure each hood within which chemical surety material is stored.

2. **What is the history of storage of chemical agents at the facility?**

HT/HD Ton containers of bulk agent have been stored at the installation since WWII. Stocks of M55 GB/VX Rockets and VX M23 land mines were shipped to PBA during the 1963-1966 time frame from off-post production sites. BZ munitions/agent have been in storage at PBA since their manufacture in the 1962-64 time period.

3. Where and when were the stockpiles manufactured?

a. HT/HD Ton Containers: PBA was a manufacturing site for mustard filled munitions during WWII; these containers/agents were shipped in from off-post sites during the post WWII era. The manufacturing site is not known.

b. GB M55 Rockets were produced at Rocky Mountain Arsenal, Colorado during the 1961-1963 time period.

c. VX M23 Land Mines and VX M55 Rockets were produced at Newport Army Ammunition Plant, Indiana during the 1961-1962 time period.

d. BZ Munitions (M43 Cluster Bombs and M44 Cluster Generators) were produced at PBA during the 1963-1964 time period. The bulk BZ Agent was commercially procured.

4. What is the policy for personnel associated with chemical agents? including:

a. Number, education, rotation: A total of 346 Pine Bluff Arsenal employees are on the Chemical Surety Position Roster, indicating that they require and have been approved for routine access to Chemical Surety Materiel under the two-man concept, or routine unescorted entry into a Chemical Exclusion Area. The education of these employees varies from less than high school, for some of the blue collar employees, to more than a baccalaureate degree for some of the administrative and professional employees. Rotation practices also vary widely; some groups such as Security Guards are regularly rotated among physical locations and job assignments whereas other groups, such as specialized craftsmen, concentrate on specific equipment at a few locations. QASAS personnel are included in a worldwide rotation program.

b. Military/civilian/contractor status: Military and civilian personnel are cleared under the provision of the Chemical Personnel Reliability Program; contractor personnel are always escorted by a properly cleared Arsenal individual.

c. Extent of security clearance at facility: PBA is classified as a controlled post and assigned military/civilian personnel are granted security clearances based upon individual job requirements. As a general rule, security guards possess a secret clearance.

d. Authorized vs. actual staff level: Priority in recruitment action is given to key position vacancies. Management endeavors to maintain strength at authorized levels in security, storage and chemical laboratory operating elements due to the critical nature of the work.

e. Qualifications of commander and other management: Personnel must be qualified under the provisions of Chapter 3 to AR 50-6, Chemical Personnel Reliability Program.

5. What is the procedure and frequency of transporting munitions and bulk agents on/off site? including:

GENERAL COMMENT ON FREQUENCY: PBA requests and receives small RDT&E quantities of chemical agent 2-3 times annually from the Chemical Research and Development Center at Aberdeen Proving Grounds, Md., to support laboratory serviceability testing workload.

a. Incident/accident history during the last two years: There have been no incidents/accidents.

b. Security during each move: Technical Escort personnel provide security to the area municipal airport, augmented by PBA DAC guards when the agent is transported to the Arsenal either by air or ground convoy.

c. Availability of emergency medical, firefighter, etc. personnel: The Arsenal's trained medical, NBC, Fire and Rescue and Security teams are available for response on a 24-hour basis and are placed on alert during each movement.

6. Present a short public affairs history for the site/facility including all local/state/regional concerns or problems and a command brochure or other public literature.

Pine Bluff Arsenal is a multi-mission installation with responsibility for production engineering and technology, laboratory, and storage activities. It is the only active Army installation within the state, and is one of the three leading employers in the geographical area. The Arsenal maintains excellent relations with the business community, and receives solid citizen support for its defense mission. Due to the Arsenal's unique role and continued mission growth both in the conventional and chemical areas, programs and projects which affect the installation, receive broad news coverage which keeps the public informed on the Arsenal and its mission. A summary and brochure is enclosed as Enclosure #1 [not reproduced here].

7. Present a summary of the operating budget requested, authorized, and appropriated in direct support of the chemical munitions program and operations for each site for FY 82-85.

(NOTE: Funding data presented below is for the identifiable major elements of work related to the CSM Stockpile. Figures presented are the same for funds required, authorized and appropriated except for FY 84 where an additional $500K has not yet been authorized for surety support but is soon expected to be.)

ACTIVITY	YEAR(K) 82	83	84	85
Surety Support (Security, IDS)	4,358	5,310	5,128	5,640
CSM Surveillance	870	907	1,478	1,626
CSM Inventory	142	249	212	233
BZ Disposal	557	201	719	1,700

8. What contingency plans for incident/accident have been developed? including:

The Arsenal maintains a Chemical Accident/Incident Control Plan (CAICP) which is officially designated as Annex C to the PBS Disaster Control Plan (DCP) which provides direction and guidance for responding to any on/off post accident/incident. Periodic tests of emergency procedures contained in this plan are conducted to evaluate adequacy and effectiveness.

a. For on-site personnel: All installation elements participate in periodic post-wide training/test exercices of emergency procedures. A trained complement of military/civilian personnel are specially trained in security, medical, detection and decontamination procedures and have the capability to be deployed to any emergency site. A system of duty and non-duty hour notifications is developed to assure timely responses. Personnel not required to participate in emergency actions are provided instructions on specific personnel protective measures required.

b. Availability of off-site assistance: PBA maintains signed Memorandums of Understanding with area Health, Hospital, Law Enforcement, Civil Defense and other governmental agencies which provide for rendering support in areas of mutual interest.

c. Impact on the surrounding community: The Arsenal maintains a close relationship with area municipal civil defense officials to assure that contingency plans are workable if implementation is required. Periodic test exercises conducted include off-post hazards and coordination with key officials who have the responsibility for off-post notifications and evacuations. Based upon these factors the Arsenal considers that although a potential hazard exists, the safety of personnel can be maintained.

9. What are the applicable local/state laws relating to chemical storage under which the facility must operate?

There are no mandated regulatory controls applicable to accomplishing the on-going storage and laboratory mission.

10. What is the proximity of non-chemical ammunition stocks stored at the facility? What hazards or procedures associated with them may affect the safety of the chemical munitions and bulk agents?

The installation's Chemical Exclusion Area contains 86 storage igloos, 3 of which contain conventional white phosphorous smoke munitions. These pose no significant hazard to the chemical munition in storage due to the quantity distance factors. Other conventional material stored exterior to the Chemical Exclusion Area similarly poses no hazards due to this same factor.

11. What periodic reports or special studies or inspections of the stocks have been completed during the last two years (including reviews by the Army, DOD, GAO, other)? Provide copies.

a. A 100% screening of the M23 VX Land Mine stockpile for detection of any Bellville Spring problems was conducted during the course of a stockpile maintenance project during the period January - May 1982. No specific report was prepared but 100 munitions were identified with this problem and set aside.

b. A representative from the DOD Explosive Safety Board (DDESB) performed a safety survey at PBA during the period 19 - 22 October 1982 which included an examination of selected storage igloos and contents. There were no significant deficiences noted.

12. What are the detailed operating procedures for handling leakers? including:

Leaking munitions are processed IAW approved SOP's for the individual items and are given priority of attention. Basically the container, if repairable, is immediately repaired and if munition or container requires overpack, this is immediately done IAW applicable regulations.

a. Disposition: PBA has had no leakers which required emergency destruction. Thirty nine leaking M-55 GB rockets were disposed of during the DATS operation conducted at PBA in FY 81. These leakers were discovered during the conduct of cyclical surveillance in preceeding years. When leaking valves and plugs on ton containers are discovered, they are either tightened or replaced--other leaking containers are overpacked.

b. Monitoring methodology: Munitions and containers are periodically monitored to assure no further deterioration of overpack containers.

c. Statistical analysis of leakers by type, lot, age, etc.: This is accomplished at Headquarters AMCCOM since other storage sites have lots similar to PBA.

1.3 Describe the present medical monitoring program for workers potentially exposed to agent and a history of the change in this procedure during the last five years.

Medical monitoring program for workers potentially exposed to agent is in accordance with DA Pam 40-8 (Chpater 3 and Appendix D) and Letter, DRCSG-O, 6 June 1983, Subject: Medical Surveillance of Personnel Potentially Exposed to Cholinesterase Inhibiting Substances. This requires the recording of time that operating personnel are potentially exposed and these records will be maintained for 40 years. This procedure was instituted in September 1982. Prior to that time, a log of entry/exit times at exclusion areas was maintained and all workers observed by the supervisor for symptoms prior to leaving the installation.

14. Describe the present environmental monitoring program and a history of the change in this program durig the last five years.

a. First entry monitoring is required prior to entering storage, operational areas, and agent laboratories utilizing approved detecting equipment and procedures. Continuous monitoring of the storage/work sites while personnel are present at the site. Monitoring is accomplished by the following approved monitoring detectors:

(1) M-8 alarms

(2) Components of M-18 kit i.e.

(a) Enzyme tickets

(b) Detector tubes

(c) M-8 paper

(3) Bubbler sampler (absorption air sampling) for H, G, VX agents

(4) Real time monitors

(5) Swab tests for BZ Agents (Ethylene glycol, 1 swab per 1 sq. ft.

(6) Visual observation for agent leakage

b. Laboratory operations with chemical agents require engineering controls (fume hoods, glove boxes) with constant monitoring of laboratory.

c. Monitoring of work areas where unprotected personnel perform duties must be accomplished by detectors capable of detecting to 0.0001 mg/m^3 for GB and 0.00001 mg/m^3 for VX and 0.003 mg/m^3 for H agent. This is accomplished at PBA by use of bubbler samplers.

15. Provide a map and aerial photograph of the site/facility and information concerning the surrounding region including:

a. Location, density of population: The installation's post population includes approximately 115 assigned military and 1,315 civilian employees in addition to approximately 120 military dependent personnel who reside on-post. The majority of the workforce perform their duties within buildings/structures located generally in the south and north post sections. An installation map is enclosed as Enclosure #2.

b. Transportation routes via air, road, water: The Arsenal is served by two major railway lines and commercial truck carriers. Quick access to major U.S. highways is available, and a U.S. Air Force Base is easily accessible by this highway system. A nearby municipal airport can accommodate military fixed and rotary wing aircraft. Commercial air transportation is obtained through the municipal airport at nearby Little Rock, AR.

c. Geophysical, climatological, seismic data: The Arsenal is situated on the interfix of the Mississippi Alluvial Plain and the Gulf Coastal Plain; its eastern perimeter is generally a bluff area facing the east, which is adjacent to the Arkansas River. The installation's elevation is approximately 250' but varies between 212-280' in the south and north post sections. Average annual daily temperatures are maximum 72.6 and minimum 49.3. The summer season is marked by prolonged periods of warm/humid weather; the winter season is generally mild but with occasional outbreaks of polar conditions.

d. Industrial facilities and operations: Pine Bluff Arsenal operates facilities for the production of smoke, pyrotechnic, incendiary and civil disturbance minutions and pollution abatement facilities in support of this mission. An incinerator complex for the disposal of non-lethal chemical materiel is also operated. Other capabilities include maintenance shops, a chemical laboratory, production engineering facilities and a variety of logistical support facilities.

and, e. Land use patterns (agriculture, grazing): The installation is generally divided into the three areas of production, administrative and depot supply; however, other support functions (including logistics, maintenance and tenant activities) are interspersed in these areas of the Arsenal's near 14,500 acres, approximately 10,000 is tree covered and included in a Woodland Management Program. Several recreational areas are available on the post for fishing, outdoor sports, picnic activities and other purposes. Hunting is also authorized on the post. No commercial outlease of Arsenal acreage is accomplished for any purpose.

16. If an accident involving chemical munitions were to occur:

a. What population groups, on/off the facilitiy, would be the primary target for protection?

The installation's emergency response is primarily geared to reacting to the maximum credible event (MCE) which at Pine Bluff Arsenal is the hazard associated with a fire occurring in a GB M55 Rocket storage igloo. The resulting 2,529 meter downwind hazard associated with this MCE is plotted on an "All directional wind" basis to identify both the on-off post population that would be within the hazard-zone. On this basis, military occupants of family quarters, and private citizens residing adjacent to he installation's western perimeter would be primary targets.

b. What dose response and exposure assessment will be used?

The installation's hazard analysis is based upon guidance contained in Technical Data Paper #10 which addresses the 1% lethality values for the agents stored at PBA. The exposure index employed in this report is the concentration time interval expressed in mgm/m^3.

c. How would calculations of wind dispersion or water seepage be determined?

The Arsenal's Operations Center, which functions during both normal and emergency operations, is equipped with real time weather monitoring instruments which are continually monitored to maintain current status of meteorological conditions--verifications of this data is made by comparisons with other instrumentation installed at various locations on the Arsenal and by contacting the nearby FAA facility. The hazard analysis computed for the specific emergency is based upon this data and is revised as conditions change. If water seepage is a factor, the installation's Environmental Coordinator is knowledgeable of data pertinent to this issue and prepared to furnish any required technical assistance in effecting response actions.

d. What are the biological/chemical and statistical uncertainties in estimating the impact?

The installation's hazard analysis program is based upon the guidance provided in Technical Data Paper #10 and is contained in the installation's computer program system. The input of variables into this program will be based upon the specific type of emergency and reliable informational sources; accordingly, the resulting hazard analysis will be highly accurate.

E

Legal Constraints

The following laws and regulations affect the Army's options for destroying chemical weapons and agents (Document 139):

1. National Environmental Policy Act, 1969 (NEPA) (PL 91--190).

   a. Requires preparation of Environmental Impact Statements (EIS) for major federal actions significantly affecting the environment.
   b. Created the Environmental Protection Agency (EPA) and Council on Environmental Quality (CEQ).

2. Air

   Clean Air Act, 1977 (PL 95-95). Establishes:

   a. National primary and secondary ambient air quality standards (primary is for protection of public health [i.e., man]; secondary is for protection of public welfare [i.e., soil, vegetation]).
   b. National emission standards for hazardous air pollutants (NESHAP) for EPA-promulgated hazardous pollutants.
   c. State implementation plans.
   d. New Source Performance Standards (NSPS) applicable to specific industries.
   e. Auto emission controls.

3. Water

   Water Quality: Clean Water Act, 1977 (PL 95-217).

   a. Promulgates national pollutant discharge elimination system.
   b. Establishes water quality criteria.

Water Supply: Safe Drinking Water Act, 1974 (PL 95-523)

a. Establishes national drinking water regulations to be implemented and enforced by the states.
b. Reproposes rules, governing protection of drinking water through application of:

(1) Primary drinking water standards applicable to contaminants that may have adverse effect on man's health.
(2) Secondary drinking water standards that are required to protect the public welfare (i.e., odor, taste).

4. Hazardous Wastes

Resource Conservation and Recovery Act, 1976 (PL 94-580).

Establishes solid waste management information and guidelines as follows:

a. Hazardous waste, defined in Section 261.3.
b. Standards applicable to generators of hazardous waste.
c. Standards applicable to transporters of hazardous waste.
d. Standards applicable to owners and operators of hazardous waste treatment, storage, and disposal facilities.
e. Permits for treatment, storage, or disposal of hazardous waste.

Recent review of regulations by the Environmental Protection Agency (EPA) (46 FR 56582-89) November 17, 1981.

a. EPA excludes certain types of mixtures of hazardous wastes:

(1) KO44: Wastewater treatment sludges from the manufacturing and processing of explosives.
(2) KO45: Spent carbon from the treatment of wastewater containing explosives.
(3) KO47: Pink/red water from TNT operations.

b. Revised law requires that the mixture itself be tested to determine whether it exhibits the characteristic of hazardous waste, and that the mixture be excluded if the combined concentrations in the resulting mixture are "no greater than 1 or 25 ppm."

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) ("Superfund") (PL 96-510)

a. Defines hazardous substances.
b. Designates reportable quantities as 1 pound.
c. Excludes from the definition of hazardous substances:

(1) Natural gas.
(2) Liquified natural gas or synthetic gas usable for fuel.
(3) Any person who causes release of a hazardous substance shall be liable for the cost of cleanup and for damages to natural resources.
(4) Pays for cleanup costs and removal measures, and may seek reimbursement from persons releasing the hazardous substance.
(5) Cannot pay for personal injury or other third-party damages.

Toxic Substances Control Act (TSCA), 1976 (PL 94-469).

a. Authorizes the federal government to require testing and to regulate problem chemicals well before they reach the production phase.
b. Its regulatory features include:

   (1) Acquisition of sufficient information by EPA to identify and evaluate potential hazards from chemicals.
   (2) Regulating the production, use, distribution, and disposal of such substances where necessary.

c. Sets up premarket notification.

Ocean Dumping: Marine Protection, Research, and Sanctuaries Act, 1972 (PL 92-532).

a. Section 101: No person, except by permit, is allowed to transport from any location any radiological, chemical, or biological warfare agent, or any high level radioactive waste for the purpose of dumping it into ocean waters. However, no permit could be issued by the EPA for "dumping of herbicide compounds intended for use in warfare activities" and "nerve gases."
b. Declares that unregulated dumping of material into ocean waters endangers human health, welfare, and amenities, and the marine environment, ecological systems, and economic potentialities.
c. Specific permit conditions are outlined in Section 103(a).

5. Lethal and Nonlethal Chemical and Biological Agents

Public Law 91-121, 1969 (Armed Forces Appropriation Authorization, 1970, which also provides for transportation and/or storage of chemical and biological weapons).

a. Prohibits use of authorized funds for the transportation and testing of lethal and nonlethal chemical and biological agents unless the secretary of defense has determined that the proposed action is in the best interests of national security.

b. Requires that the particulars of the proposed transportation or testing are made available to the then Secretary of Health, Education, and Welfare (now Health and Human services) for review and, if necessary, the recommendation of precautionary measures to protect public health and safety.
c. Requires notification of the President of the Senate and Speaker of the House of Representatives at least 10 days before any such transportation and at least 30 days before any such testing will commence, and to the governor of any state through which agents will be transported, in advance of any such transportation.
d. Restricts foreign development, storage, testing, and disposal if such violates international law.
e. Does not restrict transportation and disposal of research quantities or in an emergency when human safety is threatened.

Public law 91-441, 1970 (Armed Forces Appropriation Authorization, 1971, which provides for disposal of toxic chemical and biological weapons).

a. Amends PL-91-121 to include disposal.
b. Prohibits disposal of chemical and biological agents within or outside of the United States unless they have been detoxified or made harmless to man and the environment, except in an emergency to safeguard human life. An immediate report should be made to Congress in the event of such disposal.
c. Prohibits disposal of any munitions in international waters.

Public Law 91-672, 1971 (Foreign Military Sales Act - Amendment, which prohibits the transaction of chemical munitions into the United States from Okinawa.)

a. No funds are authorized for purpose of transporting chemical munitions from Okinawa to the United States.
b. Such funds as are necessary for the detoxification or destruction of these chemical munitions are authorized and shall be used for the detoxification or destruction of chemical munitions only outside the continental United States.

6. Occupational Health

Occupational Safety and Health Act (OSHA), 1970 (PL 92-596).

a. Threshold limit values represent conditions under which "nearly all workers may be repeatedly exposed day after day without adverse effect."

b. These limits are set forth in a booklet that is printed yearly by the American Conference of Governmental Industrial Hygienists.
c. Limits are based on the best available information from industrial experience, from experimental human and animal studies, and, when possible, from a combination of the three.

7. Annexes

USATHAMA Memorandum No. 200-2.
States USATHAMA policy, provides guidance, assigns responsibilities, and establishes procedures for the preparation of environmental documentation in accordance with NEPA.

Dept of Army Regulation No. 200-10.
Explains the Army environmental program, defines program objectives and policies, and assigns responsibilities for program management in support of the national programs for environmental protection, enhancement, and evaluation.

8. The Hazardous Materials Transportation Act of 1974 (HMTA) (Public Law 93-633) is also relevant. The law seeks to "protect the Nation adequately against the risks to life and property which are inherent in the transportation of hazardous materials in commerce." Under this act, the Department of Transportation must:

a. Designate particular quantities and forms of materials as hazardous;
b. Issue regulations for safely transporting hazardous materials in commerce;
c. Establish a register of hazardous materials transporters or those who cause such materials to be transported in commerce;
d. Administer exemptions and exclusions, and civil and criminal penalties.

HMTA is enforced through the Code of Federal Regulations, Title 49, Parts 100-199. These regulations do not apply to federal, state, or local governments that transport hazardous materials using their own employees, vehicles, and facilities. However, the existence of these regulations can be viewed to provide minimum safety guidelines for such government transporters.

F

Overview of Some Proposed Thermal Technologies

The conventional thermal processes and the "novel" processes suggested by USATHAMA contractors as having potential for disposal of chemical munition and agent stockpiles are noted in Table 13. In this appendix, the Technology Assessment Panel briefly summarizes the operational characteristics of the most promising processes.

The only two conventional thermal processes that can dispose of munitions without substantial downloading or preprocessing operations are the acid roaster and the thermal tower. In the acid-roaster concept, separate whole munitions are eroded in an acid bath to free the chemical agents from the explosives and propellants. The resultant slurry is "roasted" to destroy the agent and explosive materials, and to recover acid gases for recycling to the acid bath.

While this scheme offers some attractive features, adequate data are not currently available to determine the time required to dissolve the munitions in the acid bath or to insure that there will be no explosions in the dissolution tanks. Additional laboratory tests would be required to support a judgment on the potential benefits of this system. The acid-roaster concept appears to have a high level of risk for economic development within a 5 year period.

The thermal tower, which is in a preliminary stage of development, includes a large-volume chamber capable of processing one full pallet of munitions at a time. Localized heating in the chamber would be used to set off the explosives and gain access to the agent. The system would be designed to withstand repeated blast waves and the high velocity flying shrapnel that are associated with the detonation of explosives.

In addition to agent vapors, other gases might come from burning of propellents and explosives, and from pyrolysis of dunnage and munition fiberglass. All gaseous effluents would be decontaminated in a rich-fume incinerator. Solid products from the thermal process might include metal parts, fiberglass, and dunnage. Such solids would be heated to at least 538°C before being discharged from the system. This concept also has a high level of technical risk for economic development within the next 5 years.

Four of the 10 suggested conventional processes (see Table 13) incorporate well-established rotary kiln incineration in one form or another. In fact, JACADS and the Expedited M55 Rocket/M23 Land Mine Projects are designed to use rotary-kiln incinerators. Two questions, however, need clarification: (1) the definition of a kiln refactory material that resists agent corrosion from agents or the highly corrosive combustion products, and (2) the design of rotary seals to minimize kiln maintenance problems.

The fluidized bed process incorporates a bed of granular material as a mixing and resident chamber for a mixture of air, agent, metal parts, dunnage, and auxiliary fuel. It would burn preprocessed (maximum fragment size in the range 3 to 6 inches) munitions in the bed where the materials to be incinerated and/or decontaminated would be subjected to the turbulence, mixing, and heat exchange in the bed that should result in rapid combustion. Exhaust gases that leave the bed surface would be delivered to particulate-removal facilities. Acid-gas removal might be accomplished directly in the bed if an appropriate bed material can be found. The scheme has several advantages over other thermal processes, but technological risks and knowledge gaps may be too great for developing an economical and reliable system within the next 5 years.

The pusher-hearth concept would process all munitions in a single furnace, coupled with the same pollution control equipment now used in the Army's baseline system. This system features a simplified "front-end" arrangement in which munitions would be loaded on a tray partially filled with water. The water could serve two functions: it could allow punching of munitions packages to gain access to the agent, and it could act as a thermal sink during propellant burning. Rapid heat release could, therefore, be reduced and localized hot-spots eliminated during propellant combustion. The tray containing munitions would be pushed into an indirectly heated furnace for heating of agent and explosives. An incinerator would be used to destroy the pyrolyzed agent vapors as well as the decomposition products from the explosives and propellants. The concept shows promise, but additional work would be required to eliminate the potential for detonation in the hearth and to obtain a clear determination of life-cycle operating costs.

The molten metal process is designed to pyrolyze and incinerate agent, explosives, and propellants, yielding a molten metal and fused salt product. The process accepts either punctured whole munitions or munitions that have been cut into pieces. This system, which incorporates a novel technology with a number of knowledge gaps, appears to have a high degree of risk and does not have a high probability of development within 5 years.

The pyrolysis/molten salt concept seems to be relatively flexible. It could be capable of receiving munitions that have undergone a variety of kinds of preprocessing, including having both the agent cavity and explosive burster well penetrated or exposed. This complex, novel technology is poorly understood and has several knowledge gaps. It is not recommended for implementation at this time.

Of the proposed novel concepts that were reviewed, the in-shell combustion concept has the highest merit and should be considered for development. In-shell combustion is designed to handle several munitions simultaneously after their bursters have been removed. Individual oxygen-acetylene torches would be inserted into empty burster wells of munitions that had been placed in a combustion chamber. Each torch would pierce the burster well to expose and burn the agent inside. Each munition would act as an individual combustion chamber in which the agent would be incinerated. Such a system could also incorporate an afterburner chamber to collect combustion products and provide sufficient residence time and temperature to ensure destruction of any residual agent vapors. The exhaust gases leaving the afterburner could be dealt with by appropriate air-pollution control equipment.

This concept offers a number of advantages, including: (1) high processing rate, (2) minimal preprocessing, (3) the possibility of being trailer-mounted so that the system could be moved from one depot to another, and (4) the possibility of lower life-cycle operating costs. This concept might also be useful for decontaminating bulk containers (see Chapter 16).

Additional work is required to learn more about gaining access to the agent cavity with a torch and the degree of agent destruction within the munition before a reliable judgment can be made concerning the technological risk involved.

G

Elements of a System Safety Program

HAZARD ANALYSIS

Preliminary Hazard Analysis

A Preliminary Hazard Analysis is a comprehensive, qualitative safety evaluation of a complete system. It seeks to provide the initial safety evaluation of that system, to identify potentially hazardous or safety-critical aspects of the total program, and to formulate the safety parameters that guide all other program tasks. It identifies sources of hazards and the various means for controlling them. The analysis should be performed as early in the life cycle as possible and consider all hazards that might occur in operating the disposal system. By listing the hazards as early as possible, problems can be resolved during system design.

Subsystem Hazard Analysis

A Subsystem Hazard Analysis is an expansion of the Preliminary Hazard Analysis. It provides a more detailed look at each subsystem to determine what hazards, if any, are present and determines the result of component failure. The hazards found can then be eliminated or controlled.

System Hazard Analysis

A System Hazard Analysis is performed to determine the hazards present in a complete system. In particular, it investigates hazards that might exist at the interface between subsystems since malfunctions or failures in one subsystem might produce hazardous effects in another.

---

*Material contained in this Appendix is based on Rankin, 1978, DARCOM-R 385-23, and MIL-STD-882, 882A, and 882B.

After identifying possible hazards, the analysis indicates what action should be taken to either eliminate or control them.

Operating and Support Hazard Analysis

An Operating and Support Hazard Analysis identifies and evaluates hazards resulting from operations or tasks performed by humans. It should consider:

a. The planned system configuration or state at each phase of activity;
b. The facility interfaces;
c. The supporting tools or other equipment specified for use;
d. Operational or task sequence, concurrent task effects, and limitations;
e. Biotechnological factors, regulatory or contractually specified personnel safety and health requirements;
f. The potential for unplanned events including hazards introduced by human errors.

It should identify:

a. Activities that occur under hazardous conditions, their time periods, and the actions required to minimize risk;
b. Changes needed in functional or design requirements for system hardware and software, facilities, tooling, or support and test equipment to eliminate hazards or reduce associated risks;
c. Requirements for safety devices and equipment, including personnel safety and life support equipment;
d. Warnings, cautions, and special emergency procedures (e.g., egress, rescue, escape, render-safe, and back-out);
e. Requirements for handling, storage, transportation, maintenance, and disposal of hazardous materials;
f. Requirements for safety training and personnel certification.

Maintenance Hazard Analysis

The Maintenance Hazard Analysis is performed to identify hazards associated with system maintenance. It helps to ensure safe maintenance procedures.

Occupational Health Hazard Assessment

An Occupational Health Hazard Assessment identifies and documents health hazards and proposes protective measures to reduce associated risk to an acceptable level. The health hazards and recommended engineering controls, equipment, and/or protective procedures are identified and recommended, including those for toxic materials and physical agents. System, facility, and personnel protective equipment design requirements to safe operation and maintenance are identified.

Training

Training is required to ensure that operating personnel can recognize types of hazards and know their causes and effects as well as preventive and control measures. Other important training topics include procedures, checklists, frequently encountered or likely human errors, safeguards, safety devices, protective equipment, monitoring and warning devices, and contingency procedures. The training task involves developing lesson plans and certification requirements, which incorporate the results of system and operating hazards analyses.

Software Hazard Analysis

A Software Hazard Analysis is performed to identify hazardous conditions incident to safety-critical operator information, command, and control functions identified by the preliminary, subsystem, system, and other hazard analyses. Software design is examined to identify unsafe, inadvertent command/failure-to-command modes for resolution. Safety critical operator information and commands are traced through flow charts, software and hardware specifications, and other applicable documentation. Methodology for such analyses are described in Marchant et al. (1984).

Hazard Tracking and Risk Resolution

The purpose of this element is to establish a hazard tracking system. It requires that a method or procedure be developed to document and track hazards from their identification through their elimination or until the associated risk is reduced to an acceptable level. This provides an audit trail for hazard resolutions. A centralized file or document called a "hazard log" is maintained. If an accident ever does occur, examining such records will help determine possible causes and identify corrective actions.

Management Oversight Risk Tree

The various system safety techniques listed in Table 14 should be applied to the entire scope of the program in a timely manner and throughout the entire life cycle of the system. The safety program associated with the disposal of chemical weapons need not be limited to tasks identified in military documents. Thus, for example, the use of a Management Oversight and Risk Tree (MORT) can help to insure that there are no foreseeable management oversights.

The Department of Energy (DOE) and its predecessor agencies, the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA), spent more than a million dollars developing and testing this comprehensive approach to safety (Johnston, 1980; System Safety Development Center, 1976, 1977a, 1977b). MORT is a formal, disciplined, logic or decision "tree" to relate and systematically integrate a wide variety of safety concepts and tools. This approach is referenced in recent safety textbooks (Peterson, 1980), most of which suggest similar systems-wide programs (Brown, 1976; Hammer, 1976; Hammer, 1980; Malasky, 1982; Tarrants, 1980).

System-safety programs exist to ensure the timely and effective application of safety techniques. The Army Safety Program, delineated in MIL-STD-882B and in the AR385 series of documents, is not as thorough as MORT in some respects. MORT provides the structure to which system safety techniques can be applied. However, it is important to distinguish between the program scope discussed above and analytic techniques, which are discussed below.

ANALYTIC TECHNIQUES

Various techniques are available to provide a disciplined approach to system-safety analysis. Their purpose is to predict hazards and accident potentials, and to provide insights into their amelioration by anticipating as many causes as possible. Even given the most thorough diligence and discipline, there is no guarantee that every potential cause of accidents will be anticipated. Nevertheless, a thorough program that applies proper techniques at the appropriate time will reveal aspects of design and procedures that might otherwise be overlooked.

The available techniques can be classified as either "deductive" or "inductive." Deductive techniques start with each undesirable event that is to be minimized or avoided and logically seek to determine how that event could occur. They proceed from the undesirable end events and terminate at the component failure level. Deductive techniques would identify single, dual, and other multiples of failures that provide paths to the undesired event. They can include human-operator errors as well as equipment or component errors. Thus, deductive techniques are called "top down" approaches. They can be quantified or not.

Inductive or "bottom-up" techniques start at the component level and proceed to the consequences of a given failure mode for a component. These analyses often involve estimates of the severity and frequency of the failure to evaluate its importance. For example, the consequences of a pump failure can be traced to determine the severity of the failure, if it were to occur. The frequency can be estimated from the manufacture's reliability data.

A wide variety of detailed, analytical techniques are available for application to each specific situation. These include: operator workload analysis, energy-barrier analysis, change analysis, job safety analysis, operating hazard analysis, subsystem hazard analysis, sneak circuit analysis, fault tree analysis, Boolean mapping, failure mode and effects criticality analysis, interface analysis, and extreme value analysis, among others (Rankin, 1978; Johnson, 1980).

To use only an inductive or only a deductive technique would be an error in a program where the consequences of an accident could be severe even though the probability of occurrence is low. Using both approaches allows a check on the thoroughness of each. Thus, the undesirable end events recognized from tracing the consequences of component failures can be used to see if the essential undesired events used to start the deductive logic process are complete, and vice versa. These checks can also be used for secondary failures; i.e., failures of components that cause other failures within the system. Unless inductive and deductive approaches are used simultaneously at each phase of design and development, the cross checks for thoroughness are sacrificed. Such a sacrifice is not acceptable considering the sensitivity to safety of the chemical weapons disposal program.

H
Summary of System Costs by Category

SYSTEM	TOTAL OF EIGHT SINGLE SITES					ALL MUNITIONS COLLOCATED AT ONE SITE*					
	Facility	Capital	Production	Non-Prod.	TOTAL	Facility	Capital	Production	Non-Prod.	TOTAL	Reference
Baseline	$50.3	$246.9	$611.5	$101.7	$1010.4	$20.4	$ 80.4	$348.4	$48.2	$497.4	Shatto, 1984b
Acidroaster	45.9	140.4	414.8	88.3	689.4	21.1	69.4	338.9	43.0	472.3	Shatto, 1984b
Thermal tower	55.4	341.4	274.0	41.3	712.1	20.7	108.5	164.9	18.1	312.2	Shatto, 1984b
Rotary Kiln w/cryofract.	40.9	174.6	268.5	66.2	550.2	16.4	78.0	147.9	30.7	273.0	Shatto, 1984b
Rotary Kiln/Molten Salt Hybrid. w/cryofract.	42.8	191.5	281.8	72.1	588.2	17.8	87.8	185.2	35.0	325.8	Shatto, 1984b
Heated Chamber Rotary Kiln	60.1	388.6	297.9	56.5	793.1	34.3	222.7	204.7	29.4	491.1	Shatto, 1984b
Electric Rotary (1) Pyrolyzer & Kiln	55.0	232.8	336.9	87.1	711.8	20.6	99.2	212.0	39.3	371.1	Shatto, 1984b
Above w/cryofracture	42.9	222.6	267.5	70.1	603.1	17.6	94.5	156.6	31.7	300.4	Shatto, 1984b
Fluidized Bed w/cryofracture	42.9	180.0	287.0	70.1	580.0	17.1	77.5	166.7	33.0	294.3	Shatto, 1984b
Pusher Hearth (2)	56.0	208.7	384.0	91.1	739.8	21.4	85.3	312.6	43.3	462.6	Shatto, 1984b
Above w/cryofracture	53.5	193.6	275.7	73.7	596.5	19.4	77.5	179.3	35.4	311.6	Shatto, 1984b
Molten Metal	55.6	179.5	351.7	90.3	677.1	21.5	81.7	228.6	40.7	372.5	Shatto, 1984b
Pyrolsis/ Molten salt (3)	49.4	174.6	337.0	84.2	645.2	20.8	90.0	223.4	38.3	372.5	Shatto, 1984b
Above w/cryofracture	46.8	160.8	269.4	67.6	544.6	18.8	82.8	167.4	30.9	299.9	Shatto, 1984b
In-shell Combustion	3.7	188.2	175.7	125.1	492.7	---	---	---	---	---	Shatto, 1984b
Pyrolsis/chlorinolysis	53.7	158.8	619.2	72.5	904.2	---	---	---	---	---	Shatto, 1984b
Above w/credit for DF	53.7	158.8	176.8	72.5	461.8	---	---	---	---	---	Shatto, 1984b
Steam Pyrolsis	NA	29.0	140.0	NA	170.0+	---	---	---	---	---	Houseman, 1984
Drain-in-furnace	NA	24.0	125.0	NA	160.0+	---	---	---	---	---	Houseman, 1984
Underground Hydrol.		200.0	280.0	NA	480.0	---	---	---	---	---	Houseman, 1984
Combustion or Hydrolysis Comb.		94.0	232.0	NA	330.0	---	---	---	---	---	Houseman, 1984
Ocean Placement	Land transportation: $67.0 to 1384.0; ocean transport.: $8.6; envir. compliance: $8.6										USATHAMA, 1983c
Nuclear Explosion	Cost of disposal only: $200.0; Transportation costs not included										Duff, 1982

(1) Called Rotary Pyrolyzer - 1
(2) Called Pusher - 1 in Shatto, 1984b
(3) Called Pyrolyzer/MS - 1

*No transportation costs included. Estimates range from $200 to $900 million (Boronian Briefing, Shatto Telecon, October 18, 1983)

References

Ambrose, J. K. 1982. Letter to Martin Goland, Chairman, National Research Council's Board on Army Science and Technology. Subject: Request for study. November 10. Washington, D.C.: Under Secretary of the Army.

Army Materiel Command Regulation 385-28. 15 October 1969. Safety Regulations for Agent BZ. Washington, D.C.: Headquarters, Army Materiel Command. (181)

Army Regulation 385-16. 1 December 1980. System Safety Engineering and Management. Washington, D.C.: Headquarters, Department of the Army. (78)

Balachandran, M. and R. G. Rouz. 1982. BZ Disposal Facility Development and Design, Task I - Optimum BZ Disposal Facility Selection. Report No. DRXTH-IS-CR-82153. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (67)

Ballantyne, W. C., A. E. Weller, G. G. Zeidman and E. J. Mezey. 1981. Engineering and Technical Support of Agent BZ Disposal Processes -- Task IX -- Incineration/Detonation Studies. Report No. DRXTH-IS-CR-81114. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

Baronian, C. 1984. Personal discussion with Charles Baronian, USATHAMA, on August 23. A detailed report on VX incineration tests is in preparation by CAMDS staff.

Barrett, W. J. 1977. Requirements and Techniques for Monitoring Process for Demil of Chemical Agent Identification Sets. Report No. SORI-3828-1, SORI-EAS-77157. Southern Research Institute.

Note: Numbers in parentheses refer to document file number established by the Board on Army Science and Technology.

Battelle. 1982. Final Report for Phase I of Research and Development Services Process Development/Laboratory Studies in Support of the Munitions/Agents Process Development. Three volumes. Columbus, Ohio: Battelle Columbus Laboratories. (51)

Bereblum, I. 1935. J. Pathol. Bacteriol. 40:549-558.

Botner, H. K. and C. G. Wagner. March 5, 1984. Resolution 84-3. Madison County (Kentucky) Fiscal Court.

Brankowitz, W. 1983. Memorandum for Chief, JACADS Branch. Subject: Draining of HD vs. GB rounds (105 mm) at Anniston Army Depot (DATS). Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (149)

Brooks, M. E. and G. A. Parker. 1979. Incineration/Pyrolysis of Several Agents and Related Chemical Materials Contained in Identification Sets. ARCSL-TR-79040. Aberdeen Proving Ground, Md.: U.S. Army Armament Research and Development Command, Chemical Systems Laboratory. (105)

Brown, D. B. 1976. Systems Analysis and Design for Safety. Englewood Cliffs, N.J.: Prentice-Hall.

Carney, C. 1982. Overview of Chemical Demil Project. Briefing for NRC's Board on Army Science and Technology by Carl Carney, GA Technologies, June 20, 1983. San Diego, Calif. (53)

Carney, C. 1984. Briefing on transportation of chemical agents by Carl Carney, GA Technologies, January 12. San Diego, Calif.

Case, R. A. M. and A. J. Lea. 1955. Brit. J. Prev. Soc. Med. 9:62-72.

DARCOM. 1982. Safety Regulations for Chemical Agents GB and VX. DARCOM-R 385-102. Alexandria, Va.: U.S. Army Materiel Development and Readiness Command. (82)

DARCOM Pamphlet 385-23. 1977. System Safety. Alexandria, Va.: Army Materiel Development and Readiness Command. (80)

DARCOM Regulation 385-3. 1981. Hazard Analysis for Facilities, Equipment, and Process Developments. Alexandria, Va.: U.S. Army Materiel Development and Readiness Command. (79)

Davison, W. 1984. Chemical Agent/Munitions Disposal, Mechanical Process Research and Development. Briefing by William Davison, GA Technologies, January 11. San Diego, Calif. (123)

Defense Technical Information Center. 1977. Technical Report 7710. Problem Definition Studies on Potential Environmental Pollutants, VIII, Chemistry and Toxicology of BZ (3-quinoclidinyl benzilate) August.

Department of Defense Explosives Safety Board. 1980. Methodology for Chemical Hazard Prediction Technical Paper No. 10, Change 3. June.

Dickerson, M. H., P. H. Gudiksen, and T. J. Sullivan. 1983. The Atmospheric Release Advisory Capability. UCRL-52802-83. Livermore, Calif.: Lawrence Livermore National Laboratory.

Duff, R. E. 1982. The Feasibility of Chemical Munition Disposal Using Nuclear Explosions. Report No. SSS-R-83-5780. Contract No. DNA 001-81-C-0288. Washington, D.C.: Defense Nuclear Agency.

Dustin, D. F., M. P. Garey, S. Sudar, and S. J. Yosium. 1983. Evaluation of Alternative Thermal Processes for the Disposal of Obsolete Chemical Munitions. Report No. DRXTH-TE-CR-83213. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (61)

Edgewood Arsenal. 1971. Special Publication 100-98. Toxicological Basis for Controlling Emission of GB into the Environment. March.

Edgewood Arsenal. Special Publication 1100-1. Toxicological Basis for Controlling Emission of VX into the Environment.

Edgewood Arsenal. 1975. Special Publication 740-30. Toxicological Basis for Controlling Levels of Mustard in the Environment. June.

Ferer, K. M. 1975. Fifth Post-Dump Survey of the CHASE X Disposal Site. NRL Memorandum Report 2996. Washington, D.C.: Naval Research Laboratory.

General Atomic. 1982. Research and Development Services for Mechanical Process Development/Laboratory Studies in Support of the Munition/Agent Process Development Program. Phase I Final Report. No. GA-A16891, GACP 23-216. Volume I, Technical Report, Books 1-4. San Diego, Calif.: General Atomic Company. (52)

Gordon, J. J., R. H. Inns, M. K. Johnson, L. Leadbeater, M. P. Maidment, D. G. Upshall, G. H. Cooper, and R. L. Rickard. 1983. Arch. Toxicol. 52:71-82.

Griffin, M. 1981. Government Shipment of Carbonyl Chloride (Phosgene). DARCOM Form 2514-12 and attached correspondence. October 28.

Hammer, W. 1976. Occupational Safety Management and Engineering. Englewood Cliffs, N.J.: Prentice-Hall.

Hammer, W. 1980. Product Safety Management and Engineering. Englewood Cliffs, N.J.: Prentice-Hall.

Hasson, S. W. and J. R. Kolmer. 1978. Operation of the Drill and Transfer System at Dugway Proving Ground, Utah: Final Environmental Impact Statement. Aberdeen Proving Ground, Md.: Office of the Project Manager for Chemical Demilitarization and Installation Restoration.

Hatterick, G. R. and H. E. Price. 1980. Format Options and Procurement of Technical Orders. Report No. AFHRL-TR-80-49. Brooks Air Force Base, Tex.: HQ Air Force Human Resources Laboratory (AFSC).

Hercules, Incorporated. 1974a. Failure Mode and Hazardous Effect Analysis of the Agent Destruction System for CAMDS. Cumberland, Md.: Allegany Ballistics Laboratory.

Hercules, Incorporated. 1974b. Failure Mode and Hazardous Effects Analysis of a Deactivated Furnace and Air Pollution Control System. Cumberland, Md.: Allegany Ballistics Laboratory.

Heston, W. E. and W. D. Levillain. 1953. Proc. Soc. Exp. Biol. N.Y. 82:457-460.

Hidalgo, P. 1983. Overview of Chemical Demilitarization Programs. Briefing by Colonel Peter Hidalgo, USATHAMA, October 17. Aberdeen, Md.

Houseman, J. 1984. Novel Techniques for Disposal of Chemical Munitions. Briefing by John Houseman, Jet Propulsion Laboratory, January 11. San Diego, Calif. (118)

IARC Monograph. 1975. Vol. 9, pp. 181-192.

Irving, Solomon _et al_. 1970. Methods of Estimating Hazard Distances for Accidents Involving Chemical Agents. Operations Research Group Report No. 40. Edgewood Arsenal, Md.: Operations Research Group. February.

JACADS. Undated. Excerpt labeled "Section 3 Process Descriptions" from unidentified document--probably, Final Concept Design for JACADS.

J. M. Huber Corporation. Undated. Huber Technology Fluid - Wall (HTFW) Reactor. Technical Bulletin. Borger, Tex.: J. M. Huber Corporation. (129)

Jody, B. J., G. Chettur, R. J. Dihu, M. Schurger, and R. H. Snow. 1983. Development of Chemical Processes for Chemical Demilitarization--Phase I. Report DRXTH-TE-CR-83209. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

Johnson, W. G. 1980. MORT Safety Assurance Systems. Chicago: Marcel Dekker and New York and National Safety Council.

Jones, M. L. and L. R. Albaugh. 1974a. Failure Modes and Hazardous Effect Analysis of the Agent Destruction System for CAMDS at Tooele Army Depot, Tooele, Utah. Report No. A08202-520-03-004. Cumberland, Md.: Hercules, Inc. (143)

Jones, M. L. and L. R. Albuagh. 1974b. Final Report, Human Factors Analysis of the Agent Destruction System for CAMDS at Tooele Army Depot, Tooele, Utah. Report No. 74-70. Cumberland, Md.: Hercules Inc. (37)

Katz, M. J. 1974. Failure Modes and Hazardous Effects Analysis of a Deactivation Furnace and Air Pollution Control System. Report No. A08208-520-03-009. Cumberland, Md.: Hercules, Inc.

Larsson, L. 1957. Acta Chem. Scand. 11:1131-1142.

Lawhorne, S. E. 1974. Statistically Significant Sampling Program - Test Summary. Inclosure No. 2 for Demilitarization Plan: Operation of the Chemical Agent Munitions Disposal System (CAMDS) at Tooele Army Depot, Utah. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

Lee, K. W. and D. S. Lewis. 1983. J. M. Huber PCB Destruction Process Trial Burn Report. Borger, Tex.: J. M. Huber Corporation. (128)

Leideritz, J. Undated. Memorandum from Lieutenant Colonel James Leideritz, U.S. Army, to Howard E. Clark, Board on Army Science and Technology, transmitting information excerpted from classified letter, DRSMC-CLN-TE(A), Chemical Research and Development Center, AMCCOM, 4 April 1984. Subject: Army Requirements for Difluoro.

Little, Arthur D., Inc. 1982. Incineration Versus Neutralization for Johnston Atoll Chemical Agent Disposal System. Report No. 4505-TR-11. Contract No. DACA 87-81-C-0122. Huntsville, Ala.: U.S. Army Engineers Division. (153)

Lloyd, J. D. 1984. Memo from Director, U.S. Army DARCOM Field Safety Activity, Charlestown, Indiana, to LTC Leideritz, "Maximum Credible Events (MCE's) and 1% Lethality Distances for DARCOM Chemical Agent Storage Sites," March 2.

Lurk, P. 1981. Training Program for CAMDS Hazardous and Toxic Waste Treatment and Storage Operations. Site Plan 57-04. Tooele, Utah: CAMDS Directorate.

Malasky, S. W. 1982. System Safety: Technology and Application. New York: Garland STPM Press.

Mann and Pope. 1922. J. Chem. Soc. 121:594.

Marchant, E. J., R. G. Wright, M. C. Forrest, D. L. Henning. 1984. Safety analysis of computerized systems. Hazard Prevention. March/April 1984.

Meagher, J., S. Derby, and J. Graham. 1983. Robot safety/collision avoidance. Professional Safety. December 1983.

Mezey, E. J., T. Roy and G. A. Jungclaus. 1980. Engineering and Technical Support of Agent BZ Disposal Processes -- Task III -- Incineration Confirmation. Report No. DRXTH-IS-CR-80075. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

Mikulak, R. 1984. Briefing on Arms Control and Disarmament Activities by Robert Mikulak, U.S. Department of State, February 9. Washington, D.C.

MIL-H-46855B. 1982. Military Specification: Human Engineering Requirements for Military Systems, Equipment and Facilities. Report No. 1982-505-022/2111, 2-1. Washington, D.C.: U.S. Government Printing Office.

MIL-STD-1472C. 1981. Military Standard: Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: U.S. Government Printing Office.

MIL-STD-882B. 1983. Military Standard: System Safety Program Requirements, Washington, D.C.: U.S. Government Printing Office

Military Chemistry and Chemical Compounds. 1975. Army/Air Force Field Manual. FM 309/AFM 355-7.

Mink, W. H., H. E. Carlton, D. W. Folsom, D. R. Hopper, J. J. McNeely, and A. E. Weller. 1983. Thermal Process Development, Phase I Final Technical Report for the Period 5 May 1982 to 31 March 1983. Report No. DRXTH-TE-CR-83212. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (47)

MITRE Corporation. 1983a. Chemical Demilitarization Concepts -- Technical Evaluation. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (72)

MITRE Corporation. 1983b. Technical Evaluation -- Novel Demilitarization Concepts for Chemical Munitions. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (71)

MITRE Corporation. 1983c. Technical Evaluation -- Mechanical Demilitarization Concepts for Chemical Munitions. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (69)

MITRE Corporation. 1983d. Technical Evaluation -- Thermal Demilitarization Concepts for Chemical Munitions. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (70)

Montel, W. Undated. White paper entitled Expedited Rocket Demilitarization Program. Briefing presented by William Montel, former head of USATHAMA research program, April 5, 1984. Washington, D.C. (145)

Moynihan, P. I., L. E. Compton, J. Housemen, J. J. Kalvinskas, and J. B. Stephens. 1983. Safe Disposal Techniques for DOD Toxic Wastes - Executive Summary and Volumes I, II, III. Summary Report No. JPL D-918 and Reports DRXTH-TE-CR-83229, 30, 31. Aberdeen Proving Groud, Md.: U.S. Army Toxic and Hazardous Materials Agency. (55, 120-122)

National Academy of Sciences. 1969. Disposal Hazards of Certain Chemical Warfare Agents and Munitions. Washington, D.C.: Ad Hoc Advisory Committee of the National Academy of Sciences. June 24.

National Research Council. 1984. Assessment of Chemical and Biological Sensor Technologies. Washington, D.C.: National Research Council, Board on Army Science and Technology.

NUREG-0700. 1981. Guidelines for Control Room Design Reviews. Washington, D.C.: U.S. Nuclear Regulatory Commission.

O'Leary, J. F., A. M. Kunkel, and A. H. Jones. 1961. J. Pharmocol. Exp. Therap. 132:50-57.

Parsons, Ralph M., Company. 1983a. Final Concept Design. Volume I. Design Analysis: Johnston Atoll Chemical Agent Disposal System. Huntsville, Ala.: U.S. Army Engineers Division. (95)

Parsons, Ralph M., Company. 1983b. Artists Rendering of Munitions Demilitarization Machine for JACADS. Johnston Atoll Chemical Agent Disposal System. Huntsville, Ala.: U.S. Army Engineers Division. (148)

Parsons, Ralph M., Company. 1983c. Preliminary Hazards Analysis of Final Concept Design: Johnston Atoll Chemical Agent Disposal System. Task G-5C Interim Report. Ralph M. Parsons Co., Delaware. (102-2)

Parsons, Ralph M., Company. 1983d. Safety Design Reviews. Task G-5B Preliminary Report. Ralph M. Parsons Co., Delaware. (102-1)

Parsons, Ralph M., Company. 1983e. Preliminary Hazards Analysis of Final Concept Design: Johnston Atoll Chemical Agent Disposal System. Task G-5C Interim Report. Ralph M. Parsons Co., Delaware. (102-3)

Parsons, Ralph M., Company. 1983f. Human Factors Engineering Criteria for Johnston Atoll Chemical Agent Disposal System. Huntsville, Ala.: U.S. Army Engineers Division. (38)

Parsons, Ralph M., Company. Undated. Detailed design drawings for JACADS facility. Huntsville, Ala.: U.S. Army Engineer Division. (110)

Paulick, J. S. 1983a. Briefing on CAMDS presented at the Chemical Disarmament Verification Workshop. November 15-16 1983. Tooele Army Depot, Utah. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (134)

Paulick, J. S. 1983b. Briefing on CAMDS Operations by Joseph S. Paulick, Director for CAMDS, December 8. Tooele Army Depot, Utah.

Potter, R. 1983. Safety for robotics. Professional Safety. December 1983.

Pugh, D. L., et al. 1970. Incineration of GB and Containment of Gaseous Products. Report No. EATR 4463. Aberdeen Proving Ground, Md.: U.S. Army Armament Research and Development Command, Chemical Systems Laboratory.

Rankin, J. E. 1978. Safety Manual No. 15. System Safety Engineering National Mine Health and Safety Academy. Washington, D.C.: U.S. Government Printing Office.

Reeves, A. M. and G. C. Kortz. 1954. Thermal Decomposition of GB. Report No. CRLR 393. Aberdeen Proving Ground, Md.: U.S. Army Armament Research and Development Command, Chemical Systems Laboratory.

RFP# DAAD11-84-R-007. 1983. Request for Proposals: Advanced Chemical Demil System Development. Aberdeen Proving Ground, Md.: Chemical/ Ballistics Procurement Division.

Roux, R. G. 1984. Expedited M55 Rocket Disposal. Briefing by Richard G. Roux, USATHAMA, April 6. Washington, D.C.

Schultz, T. H., V. R. Daiga, J. K. Shah, T. J. Kuhn, and C. A. Hersch. 1983. Thermal Process Development, Phase I Final Report, Concept Development. Report No. DRXTH-TE-CR-83214. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (54)

Scott, J. A. 1984a. Personal discussion with John A. Scott, USATHAMA, July 9.

Scott, J. A. 1984b. Briefing on Long-range Demilitarization Program-Baseline Costs by John A. Scott, USATHAMA, March 2. Washington, D.C.

Seat, F. D. 1984. Acceptance Testing of the Rocket Shear Machine Breadboard. Test Report No. C31-206.08.003-1. Tooele Army Depot, Utah.: Directorate for Ammunition Equipment. (147)

Shappert, L. B., Carnes, S. A., et al. 1983. Collocation Alternatives for Demilitarization of the Lethal Chemical Stockpiles. Oak Ridge National Laboratory Chemical Technology Division. ORNL/CF-83-278. (Final Draft). Oak Ridge, Tenn.: Oak Ridge National Laboratory. (141)

Shatto, A. 1983a. Briefing on R&D Program in Support of Chemical Demilitarization Program by Allen Shatto, USATHAMA, October 18. Aberdeen, Md.

Shatto, A. 1983b. Expedited M55 Rocket Project. Briefing by Allen Shatto, USATHAMA, October 18. Aberdeen, Md.

Shatto, A. 1984a. Personal communication.

Shatto, A. 1984b. Systems Analysis of Competing Technologies. Briefing by Allen Shatto, USATHAMA, February 9. Washington, D.C. (132)

Staniev, C. J. Undated(a). Final Report of the Shipment of Phosgene for Disposal by Resale, Part I (From Palacios, Texas, to Lockport, New York). Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

Staniev, C. J. Undated(b). Final Report of the Shipment of Phosgene for Disposal by Resale, Part II (From Rocky Mountain Arsenal, Colorado, to Lockport, New York). Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

Stowe, W. W. 1983. Robots - safe or hazardous? Professional Safety. December 1983.

Surkein, R. J. 1970. USAMC OPLAN CHASE. Revised as of 23 Jul 70. AMSMU DS-TM Distribution cover with document attached. Dover, N.J.: Dept. of the Army Headquarters, U.S. Army Munitions Command.

System Safety Development Center. 1976. MORT User's Manual. Idaho Falls, Idaho: USERDA/EG&G.

System Safety Development Center. 1977a. Standardization Guide for Construction and Use of MORT-Type Analytic Trees. Idaho Falls, Idaho: USERDA/EG&G.

System Safety Development Center. 1977b. Safety Information System Guide. Idaho Falls, Idaho. USERDA/EG&G.

Tarrants, W. E. 1980. The Measurement of Safety Performance. New York: Garland STPM Press.

The Merck Index, 9th Edition, p. 819. 1976. Rahway, N.J.: Merck Co.

TRW. 1975. Safety Analyses and Hazard Evaluation Report Failure Modes and Effects Analysis for CAMDS. Redondo Beach, Calif.: TRW Environmental Services. (104)

U.S. Army. 1983a. United States Detailed Views on the Contents of a Chemical Weapons Ban. Committee on Disarmament Document No. CD/343. February 10. GE.83-60308. Washington, D.C.: U. S. Department of State.

U.S. Army. 1983b. Illustrative On-Site Inspection Procedures for Verification of Chemical Weapons Stockpile Destruction. Committee on Disarmament Document No. CD/387. July 6. GE.83-62194. Washington, D.C.: U.S. Department of State.

U.S. Army. 1983c. Workshop on Verification of Chemical Weapons Stockpile
Destruction. Committee on Disarmament Document No. Cd/419. August 23. GE.83-63904. Washington, D.C.: U.S. Department of State.

U.S. Army. 1984. Draft Convention on the Prohibition of Chemical Weapons. Committee on Disarmament Document No. CD/500. April 18. GE.84-61689. Washington, D.C.: U.S. Department of State. (153)

U.S. Army. 1977. Operation of the Chemical Agent Munitions Disposal System (CAMDS) at Tooele Army Depot, Utah - Final Environmental Impact Statement. Enclosure No. 2 - Agent Detoxification. Aberdeen Proving Ground, Md.: Office of the Project Manager for Chemical Demilitarization and Installation Restoration. (13)

U.S. Army. 1981a. Tooele Army Depot RMT After Action Report. Volumes 1, 2, 3, and 4. Tooele, Utah: Tooele Army Depot

U.S. Army. 1981b. March. Transportation of Chemical Material Oplan RMT, Basic Plan with Change 2. Alexandria, Va.: U.S. Army Material Development and Readiness Command.

U.S. Army. 1981c. October 1981. After Action Report. Transportation of Chemical Material. Operation RMI (August 1981). Volumes I, II, and III. Alexandria, Va.: U.S. Army Materiel Development and Readiness Command.

U.S. Army Material Development and Readinesss Command. 1980. Handbook for Chemical Hazard Prediction DARCOM Handbook No. 385-2.1-80, pp. 8-6 to 8-8. February.

U.S. Army Munitions Command. 1969. OPERATION CHASE. Plan for Disposal of Chemical Munitions Dover. N.J.

U.S. Navy. 1975. Interservice Procedures for Instructional Systems Development. NAVEDTRA-106A.

USATHAMA. 1979. Operation of the Chemical Agent Munitions Disposal System (CAMDS) at Tooele Army Depot, Utah. Enclosure No. 20: Demilitarization Protective Ensemble (DPE) Development and Evaluation Report. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency.

USATHAMA. 1982a. Long Range Chemical Demilitarization Concept Study - Revised. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (46)

USATHAMA. 1983a. Final Demilitarization Plan for Operation of the Chemical Agent Munitions System (CAMDS) at Tooele Army Depot, Utah. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (45)

USATHAMA. 1983b. Memorandum for Department of Health and Human Services. Subject: Historical Summary of CAMDS GB Agent Tests. DRXTH-SE-C. June 24. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (22)

USATHAMA. 1983c. Regulatory Impacts on the Cost of Chemical Demilitarization. Aberdeen Proving Ground, Md.: U.S. Army Toxic and Hazardous Materials Agency. (42)

Van Horn, K. R., ed. 1967. Pp. 300 - 303 in Aluminum, Vol. 2, Design and Application. Metals Park, Ohio: American Society for Metals.

Vesely, W. E., F. F. Goldbert, N. H. Roberts, and D. F. Jaasl. 1981. Fault Tree Handbook. NUREG 0492, Systems and Reliability Research. Washington, D.C.: Nuclear Regulatory Commission.

Whelan, R. 1983a. Briefing on chemical waste disposal activities in other nations by Robert Whelan, USATHAMA, December 7. Salt Lake City, Utah.

Whelan, R. 1983b. Briefing on Johnston Atoll Chemical Agent Disposal System by Robert Whelan, USATHAMA, October 17. Aberdeen, Md.

Whelan, R. 1984a and 1984b. Personal communication with Robert Whelan, USATHAMA, August 25.

Whitacre, C. G. 1981. Computer Programs for Change 3. DODESB TP 10 (addendum to ARCSL-TR-80048). Chemical Systems Laboratory Technical Report ARCSL-TR-81016. Aberdeen Proving Ground, Md. March.

Whitacre, C. G., and L. Kneas. 1980. Revised Field Handbook for Computing Chemical Hazard Distances. Chemical Systems Laboratory Technical Report ARCSL-TR-80048. Aberdeen Proving Ground, Md. October.

Whitacre, C. G., and M. M. Myirski. 1983. (Rev. January 1983). Computer Program for Report ARCSL-TR-82014. Aberdeen Proving Ground, Md. September.

Wilson, J. G. and F. C. Fraser, eds. 1977. Handbook of Teratology, Vol. I, pp. 357-385. New York: Plenum.

Wynne, D. J. 1973. Pilot Scale Incineration of GB and VX and Containment of Gaseous Products. Report No. EATR 4734. Aberdeen Proving Ground, Md.: U.S. Army Armament Research and Development Command, Chemical Systems Laboratory.

Yurow, Harvey W. 1981. Decontamination Methods for HD, GB, and VX, A Literature Survey. ARCSL-SP-80032. Aberdeen Proving Ground, Md.: U.S. Army Armament Research and Development Command, Chemical Systems Laboratory. (131)

Yurow, H. W. and G. T. Davis. 1982. Decontamination and Disposal Methods for Chemical Agents - A Literature Survey. Report No. ARCSL-TR-81080. Aberdeen Proving Ground, Md.: U.S. Army Armament Research and Development Command. (94)

Glossary of Acronyms

AAP	Army Ammunition Plant
AD	Army Depot
AEC	Atomic Energy Commission
AMCCOM	U.S. Army Armament, Munitions and Chemical Command
ANAD	Anniston Army Depot
APG	Aberdeen Proving Ground
APIMS	Atomospheric Pressure Ionization Radio Frequency Mass Spectrometer
AR	Army Regulation
ARAC	Atomospheric Release Advisory Capability
BZ	3-Quinuclidinyl Benzilate (a hallucinogenic agent)
CAI	Chemical Accident/Incident
CAIC	Chemical Accident/Incident Control
CAMDS	Chemical Agent Munitions Disposal System
CAMPACT	Chemical Ammunition Package Transporter
CAMS	Central Atmopheric Monitoring System
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
CK	Cyanogen Chloride (a blood agent)
CONUS	Continental United States

CX	Phosgene Oxime (a blister agent)
DA	Depot Activity
DARCOM	United States Army Materiel Development and Readiness Command, now U.S. Army Materiel Command (AMC)
DARCOM-R	DARCOM Regulation
DATS	Drill and Transfer System
DDESB	Department of Defense Explosives Safety Board
DESCOM	Depot Systems Command
DF	Methyl Phosphonic Difluoride
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
GAO	General Accounting Office
GB	Sarin, $C_4H_{10}FO_2P$ (a nerve agent)
H	Mustard (a blister agent)
HD	Distilled Mustard, $Cl(CH_2CH_2)_2S$ (a blister agent)
HF	Human Factors Engineering
HMTA	Hazardous Materials Transportation Act
HT	Mustard-T Mixture (a blister agent)
ID	Identification

JACADS	Johnston Atoll Chemical Agent Disposal System
LBDA	Lexington-Blue Grass Depot Activity
LC_{t50}	Median Lethal Dosage
LD_{50}	Median Lethal Dose
MCA	Military Construction, Army (a category of appropriated funds)
MCE	Maximum Credible Event
MIL-H	MIL-CODE-H, Unserviceable, Unrepairable or Obsolete
MIL-STD	Military Standard
MORT	Management Oversight and Risk Tree
NAAP	Newport Army Ammunition Plant
NEPA	National Environmental Policy Act
NESHAP	National Emmission Standard for Hazardous Air Pollutants
NSPS	New Source Performance Standards
NUREG	Nuclear Regulation
ORNL	Oak Ridge National Laboratory
PBA	Pine Bluff Arsenal
PG	Proving Ground
PL	Public Law
PUDA	Pueblo Depot Activity
RCRA	Resource Conservation and Recovery Act
RDT&E	Research, Development, Test, and Evaluation (a category of appropriated funds)
RFP	Request for Proposal

SAC	Strategic Air Command
SB	Supply Bulletin
SDA	Skill Performance Aid
STPML	Stockpile Test Program, Metallurgical
SUPLECAM	Surveillance Program, Lethal Chemical Agents and Munitions
TC	Ton Container
TCM	Toxic Chemical Munition
TEAD	Tooele Army Depot
TECOM	U.S. Army Test and Evaluation Command
TLV	Threshold Limit Value - the maximum exposure that is permitted
TM	Technical Manual
TNT	Trinitrotoluene (a high explosive)
TWA	Time Weighted Average
UMDA	Umatilla Depot Activity
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
VX	$C_{11}H_{26}NO_2PS$ (a nerve agent)
WESCOM	U.S. Army Western Command

Glossary of Terms

Binary Weapon	A new type of chemical weapon, in which two non-toxic chemicals are used to create a toxic chemical agent in the projectile after the projectile is fired at a target.
Code A	Serviceable.
Code G	Missing a component.
Code H	Unserviceable, unrepairable or obsolete.
Collet	A metal collar used in disassembly of chemical munitions.
Difluoro	Methyl phosphonic difluoride, one of two chemicals to be used in binary weapons.
Dunnage	Materials, usually timber, used in warehousing, on which supplies are stacked.
5X	5X decontamination state, material rendered safe for salvage and sale.
Igloo	A reinforced concrete, earth covered shelter used for the storage of explosives and munitions.
Leaker	A chemical munition, from which a chemical agent has leaked as a result of deterioration or mishandling.
Maximum Credible Event	A worst-case (credible) accidental release of a chemical agent.
M23	A land mine that contains a chemical agent.

M55	An aerial rocket weapon that contains a chemical agent.
MCl MK94	An aerial bomb that contains a chemical agent.
Thermite	A chemical substance that produces sufficient heat to burn through heavy-walled steel munitions.
3X	3X decontamination state, metal components that have been chemically decontaminated, such that no agent can be detected on the metal surface.
Uploaded	This pertains to chemical munitions that have had explosive burster charges installed to improve military readiness.
Wet-Eye	A type of U.S. Navy bomb containing a chemical agent.