ANL/EAD/TM-101
Volume 1

Technology Resource Document for the Assembled Chemical Weapons Assessment Environmental Impact Statement
Volume 1: Overview of the ACWA Program and Appendixes A–E

Environmental Assessment Division

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Volume 1: Overview of the ACWA Program and Appendixes A–E

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CONTENTS

CONTENTS (Cont.)

CONTENTS (Cont.)

TABLE

FIGURES

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NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this document. Some acronyms used in tables or figures only are defined in the respective tables or figures.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

ACW	assembled chemical weapons
ACWA	Assembled Chemical Weapons Assessment
AEL	airborne exposure limit
$AgNO_3$	silver nitrate
ANAD	Anniston Army Depot
ANL	Argonne National Laboratory
APG	Aberdeen Proving Ground
ATP	Alternative Technology Program (development of chemical agent neutralization process)
BGAD	Blue Grass Army Depot
BRA	brine reduction area (baseline post-treatment drum drier equipment)
CBDCOM	U.S. Army Chemical and Biological Defense Command
CFR	Code of Federal Regulations
CH_4	methane
CMDA	Chemical Material Destruction Agency
CO	carbon monoxide
CO_2	carbon dioxide
Composition A5	a high explosive composed of approximately 98.5% RDX and 1.5% stearic acid
Composition B	a high explosive composed of 60% RDX, 39% TNT, and 1% wax
CST	continuous steam treater
CWC	Chemical Weapons Convention
DA	U.S. Department of the Army
DACWA	Dialogue on Assembled Chemical Weapons Assessment
DCD	Deseret Chemical Depot
DFS	deactivation furnace system (baseline furnace consisting of a rotary retort and a heated discharge conveyer [HDC])
DGIR	data gap identification report
DGRR	data gap resolution report
DGWP	data gap work plan
DOD	U.S. Department of Defense
ECR	explosion-containment room
EDS	engineering design study

EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERH	energetics rotary hydrolyzer
GB	sarin (nerve agent), O-isopropyl methylphosphonofluoridate
GPCR	Gas-Phase Chemical Reduction™
H	undistilled sulfur mustard, bis(2-chloroethyl)sulfide
HD	distilled sulfur mustard, bis(2-chloroethyl)sulfide
HDC	heated discharge conveyor (baseline electric radiation tunnel furnace)
HEPA	high-efficiency particulate air (type of filtration system)
HNO_3	nitric acid
HT	blister agent, mustard agent (H) with T
JACADS	Johnston Atoll Chemical Agent Disposal System
LIC	liquid incinerator
M1	charge, propellant (105-mm projectiles)
M104	projectile, 155 mm, chemical agent (H or HD)
M110	projectile, 155 mm, chemical agent (H or HD)
M2	cartridge, 4.2-in., chemical agent (HD or HT)
M23	land mine, 13-in.-diameter and 5-in.-high munition filled with VX
M28	propellant grain (M55 rocket)
M2A1	cartridge, 4.2-in., chemical agent (HD or HT)
M360	cartridge, 105 mm, chemical agent (GB)
M360	shell, 105 mm, chemical agent (GB)
M360	shell, 105 mm, chemical agent (H or HD)
M417	M55 rocket fuze
M426	projectile, 8-in. chemical agent (GB or VX)
M55	rocket, 115 mm, chemical agent (GB or VX)
M56	warhead, 115 mm, rocket chemical agent (GB or VX)
M6	charge, propellant powder (4.2-in. mortar)
M60	cartridge, 105 mm, chemical agent (H or HD)
M60	rocket, 115 mm, inert
M61	rocket, practice 115 mm, simulant (EG)
MPF	metal parts furnace (baseline tunnel furnace for drained munitions bodies)
MPT	metal parts treater
NaOH	sodium hydroxide
NRC	National Research Council
PAS	pollution abatement system (common emission control system consisting of quench cooling, chemical scrubbing, filtration, etc.)
PBA	Pine Bluff Arsenal
PCB	polychlorinated biphenyl

PCD	Pueblo Chemical Depot
PMACWA	U.S. Department of Defense, Program Manager for Assembled Chemical Weapons Assessment
PMCD	U.S. Army, Program Manager for Chemical Demilitarization
PRH	projectile rotary hydrolyzer
RCRA	Resource Conservation and Recovery Act
RDX	cyclotrimethylenetrinitramine (a high explosive)
RFP	request for proposal
SAIC	Science Applications International Corporation
SCWO	supercritical water oxidation
T	bis(2-chloroethylthioethyl) (combined with HD to make HT)
TC	ton container
TNT	2,4,6-trinitrotoluene (a high explosive)
TOCDF	Tooele Chemical Agent Disposal Facility
TRBP	thermal reduction batch processor
TRD	technical resource document
TW-SCWO	transpiring wall-supercritical water oxidation
UMDA	Umatilla Depot Activity
VX	methylphosphonothioic acid (nerve agent), O-ethyl S-(2-diisopropylaminoethyl)
1X, 3X, 5X	U.S. Army system for material safety hazard classification (X, XXX, and XXXXX, respectively)

UNITS OF MEASURE

°C	degree(s) Celsius
cm	centimeter(s)
°F	degree(s) Fahrenheit
ft	foot (feet)
in.	inch(es)
kg	kilogram(s)
kW	kilowatt(s)
lb	pound(s)
m	meter(s)
mm	millimeter(s)
MPa	megapascal(s)
ppm	part(s) per million
psia	pound(s) per square inch, absolute
t	metric ton(s)
ton	short ton(s)

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TECHNOLOGY RESOURCE DOCUMENT
FOR THE
ASSEMBLED CHEMICAL WEAPONS ASSESSMENT
ENVIRONMENTAL IMPACT STATEMENT

VOLUME 1:
OVERVIEW OF THE ACWA PROGRAM
AND APPENDIXES A–E

by
T. Kimmell, S. Folga, G. Frey, J. Molberg, P. Kier,
B. Templin, and M. Goldberg

1.1 INTRODUCTION

1.1.1 OVERVIEW OF ACWA

The U.S. Department of Defense (DOD), through the Assembled Chemical Weapons Assessment (ACWA) Program, is pursuing technologies other than baseline incineration for the destruction of chemical weapons in the U.S. stockpile. The ACWA Program was mandated by Congress through passage of the National Defense Appropriations Act for Fiscal Year 1997, Public Law 104-208, to "identify and demonstrate not less than two alternatives to the baseline incineration process." Congress did not define baseline incineration and assembled munitions in Public Law 104-208. However, the DOD previously defined baseline incineration as the technology and process design that was used at the Johnston Atoll Chemical Agent Disposal System (JACADS), located on Johnston Island in the Pacific Ocean (PMCD 1988). ACW destruction at JACADS has been completed. Baseline incineration is currently being used at the Tooele Chemical Agent Disposal Facility (TOCDF), located at the Deseret Chemical Depot (DCD) in Utah.

The DOD Program Manager for the Assembled Chemical Weapons Assessment (PMACWA) defines ACW as munitions containing both chemical agents and energetic materials (e.g., propellants, explosives) that are stored in the U.S. unitary[1] chemical weapons stockpile. This stockpile consists of ACW stored at eight different locations. ACW include rockets, projectiles, mortars,[2] and land mines. Unitary agents contained in ACW include chemical blister

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[1] The term "unitary" refers to the use of a single hazardous compound (i.e., chemical agent) in the munitions. In contrast, "binary" chemical weapons use two relatively nonhazardous compounds that are mixed together to form a hazardous or lethal compound after the weapon is fired or released.

[2] Mortars are often defined as a type of projectile or cartridge.

agents (i.e., the mustard agents H, HD, and HT) and chemical nerve agents (i.e., GB [sarin] and VX) (CBDCOM 1997).

From proposals received in response to the solicitation for demonstration testing, the PMACWA selected six independent proposers who presented systems for the destruction of ACW. These six technology systems were subjected to demonstration testing in two phases; three technologies were evaluated during Phase I (referred to as Demo I), and three technologies were evaluated during Phase II (referred to as Demo II). Demo I testing was conducted in spring 1999, and Demo II testing was conducted in summer 2000. The PMACWA has determined that four of these technology systems are acceptable for use in destroying ACW: two technology systems demonstrated during Demo I and two technology systems demonstrated during Demo II. The systems are as follows:

- Demo I
    - Neutralization/Solid Wall-Supercritical Water Oxidation (SCWO)
    - Neutralization/Biotreatment
- Demo II
    - Neutralization/Gas-Phase Chemical Reduction™/Transpiring Wall-Supercritical Water Oxidation (TW-SCWO)
    - Electrochemical Oxidation

Engineering design studies (EDSs), which are part of the ACWA demonstration test phase, are being implemented for each technology. The DOD determined that these studies were necessary in preparation for full-scale pilot design and permitting. While EDSs have been completed for the Demo I technologies, they have not been completed for the Demo II technologies. Thus, this TRD presents information on each technology as of the completion of demonstration testing.

Section 1.3 of this report presents an expanded discussion on the process used to demonstrate technologies.

1.1.2 DOCUMENT PURPOSE

This technical resource document (TRD) describes application of the above technology systems to ACW stored at four locations within the U.S. Army's unitary chemical stockpile installations. The stockpiles are located at Anniston Army Depot (Alabama), Pine Bluff Arsenal (Arkansas), Pueblo Chemical Depot (Colorado), and Blue Grass Army Depot (Kentucky). Only the ACWA Demo I technologies are discussed for Pueblo Chemical Depot (PCD). The National Defense Authorization Act for Fiscal Year 2001 (Public Law 106-398) specifically indicates that only ACWA technologies that were demonstrated on or before May 1, 2000, may be considered for PCD. This limitation effectively precludes consideration of the Demo II technologies for PCD.

This TRD presents a comparison of technical and process information on each of the destruction technologies applicable to treating the ACW. This document provides primary support for preparation of an environmental impact statement (EIS) that evaluates alternative technologies for pilot-scale testing at the four sites (PMACWA 2001a).

This TRD describes the technology systems that have been demonstrated by the PMACWA to be viable for treating ACW under the ACWA program. The subsequent volumes of this TRD describe each of the technologies in detail and present data on technology system design and implementation. The data and information presented reflect each of the ACWA technology systems as they were described following completion of the PMACWA demonstration testing program. Because of the evolving nature of the ACWA program, some of the technology systems may have since changed, and data representing design parameters also may have changed.

1.1.3 TERMINOLOGY

As prescribed by Public Law 104-208, the ACWA program must provide a "total solution" for addressing ACW, including munitions access, agent treatment, energetics treatment, metal parts treatment, dunnage[3] treatment, and effluent management and pollution controls. Therefore, each total solution proposed in the ACWA program is composed of a group of interrelated technologies, many of which have multiple units and processes. This section provides definitions of the terminology used in this report to describe the technologies that compose the ACWA total solutions.

System – A complete, total solution approach to weapons destruction that includes disassembling a weapon, accessing agent and energetic fills, destroying agent and energetics, treating component parts (metal and dunnage), and managing and disposing of effluents. Each system potentially may be considered as an alternative action under the National Environmental Policy Act.

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[3] Dunnage is a term used to describe packing materials for ACW and consists primarily of wood, cardboard, and metal. Some wastes resulting from primary treatment of ACW (often referred to as secondary waste), such as used personal protective equipment, may also be treated along with dunnage.

Process – A category of activity that contributes to a total system solution. The process categories are munitions access, agent treatment, energetics treatment, dunnage treatment, metal parts treatment, and effluent management and pollution controls.

Technology – The technique or techniques employed to accomplish each of the processes. A process may employ more than one technology. For example, both cryofracture and fluid-abrasive cutting are technologies that may be used separately or in tandem for munitions access.

Unit or Unit Operation – A single assembly of equipment used to accomplish a specified processing step. For example, cryofracture (for munitions access) consists of cryogenic baths, robotic transports, and a fragmentation press. Each of these represents one unit operation within the cryofracture technology.

Installation – The U.S. Army activity or depot used to store ACW, where pilot-testing an ACWA system is being evaluated. This includes both the chemical and the nonchemical areas of the facility. It is the entire parcel of land owned by the U.S. Army.

Facility – The structure to be built on the installation for the ACW destruction activity (e.g., the Chemical Demilitarization Facility).

Site – This term refers both to the location on the installation where ACW are currently stored and to the location on the installation where the facility for ACW destruction will be built.

1.1.4 DOCUMENT OVERVIEW

This TRD is organized as a five-volume set (Figure 1.1). The five volumes include this overview and one volume for each of the four installations that stockpile ACW. Volume 1 provides programmatic information on the technologies associated with ACW remediation. The four remaining volumes provide details regarding the application of ACWA technology systems to ACW at the four stockpile locations: Anniston Army Depot (ANAD), Pine Bluff Arsenal (PBA), Pueblo Chemical Depot (PCD), and Blue Grass Army Depot (BGAD).

To adequately assess the ACWA situation at any given U.S. Army facility, Volume 1 and the volume specifically dedicated to the facility of interest should be reviewed.

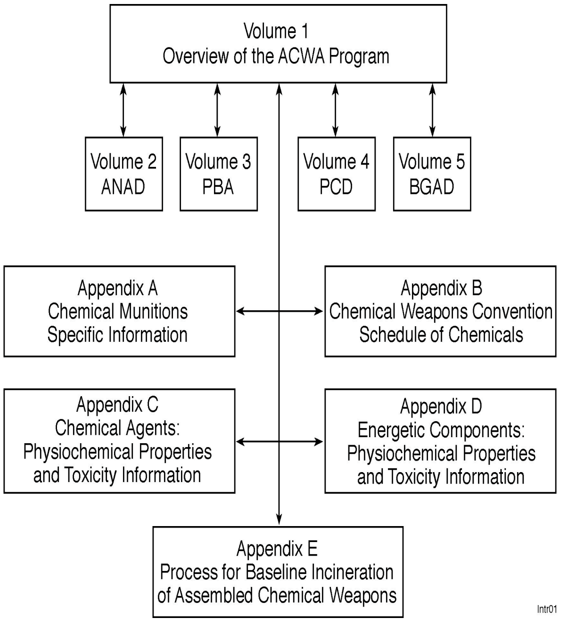

FIGURE 1.1 Organization of Technical Resource Document

Section 1.2 of this volume provides an overview of the ACW unitary stockpile. The section identifies all stockpile locations, the types of munitions contained in the stockpile at each location, and the chemical agents and energetic materials in the various ACW; it also provides chemical and physical property information for these chemicals.

Section 1.3 provides an overview of the DOD's process for selecting the ACWA technologies. As this section indicates, demonstration testing for the Demo I and Demo II technologies has been completed.

Section 1.4 identifies and summarizes each of the primary technologies that make up the technology systems. With little or no modification, many of the technologies are interchangeable among systems. Others are stand-alone or unique technologies applicable to only one system.

Finally, Section 1.5 provides a list of references that were used in preparing this volume of the TRD. Included are the PMACWA's periodic reports to Congress providing information on the progress of the ACWA program (PMACWA 1997, 1998, 1999b, 2000b, 2001c).

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1.2 DESCRIPTIONS OF ASSEMBLED CHEMICAL WEAPONS

The ACW addressed in this TRD include rockets, projectiles and mortars, and land mines. Unitary agents include chemical blister agents (i.e., the mustard agents H, HD, and HT) and chemical nerve agents (i.e., GB [sarin] and VX) (CBDCOM 1997).

The stockpile and agent and energetic components of the munition types stored in the stockpile are described in the subsections below. Additional information can be found in five appendixes that have been developed to support this resource document:

Appendix A: Chemical Munitions Specific Information (App. J3 from CBDCOM 1997)

Appendix B: Chemical Weapons Convention (CWC) Schedule of Chemicals

Appendix C: Chemical Agents – Physiochemical Properties and Toxicity Information

Appendix D: Energetic Components – Physiochemical Properties and Toxicity Information

Appendix E: Process for Baseline Incineration of Assembled Chemical Weapons

This section describes all ACW and their chemical and energetic contents. Different or modified component treatment technologies are often required for the different ACW configurations maintained at the various stockpile locations. Thus, it is critical to understand that a technology or unit that can be applied to one type of ACW may not be applicable to another type of ACW.

1.2.1 ACW STOCKPILE

The original ACW unitary stockpile contained approximately 31,500 tons (28,576 t) of unitary agents (Pacoraro 1999, as cited in NRC 1999) stored in a variety of ACW and bulk containers (e.g., ton containers [TCs]).

The ACW at JACADS have been destroyed using the baseline incineration process. The ACW at DCD are presently being destroyed using this process. Currently, baseline incinerator systems are being constructed at other stockpile locations, specifically, at PBA, ANAD, and Umatilla Depot Activity (UMDA).

Figure 1.2 identifies all the unitary stockpile locations. Table 1.1 provides an inventory (as of November 1999) of the various types of chemical munitions in storage at these installations.

In addition to the above, each stockpile site is used to store ACW that have leaked, known as "leakers."[4] Leakers are stored as hazardous waste in overpack containers. Contaminated dunnage may be stored along with the leakers. Leakers are included in the ACW inventory. Although additional precautions are taken when handling leakers, essentially the same technologies can be used to treat the munition components.

1.2.2 COMPONENTS OF ACW

1.2.2.1 ACW Types and Configurations

The ACW stockpile contains a variety of munition types, each developed for a specific military purpose. The three basic ACW types are projectiles (including mortars), rockets, and land mines.[5] ACW consist of two basic components: an agent reservoir and an explosive train. Each of the various ACW stored at the stockpile sites may be stored in different configurations. For example, some ACW contain fuzes, boosters, bursters and/or propellants, while the same type of ACW may be stored without one or more of these components. Rockets and land mines are typically stored with their energetic components in place, while projectiles (including mortars) may or may not contain bursters or fuzes. Projectiles with their propelling charges are called cartridges. Reconfiguration operations are conducted on cartridges to remove the propelling charges prior to demilitarization. Only the rockets have propelling charges during actual demilitarization.

The three basic munition types are described below. These descriptions were adapted from Appendix A of NRC 1999, which cites three references (PMCD 1988, CBDCOM 1997, SAIC 1996). Appendix A of this document provides detailed information on the ACW configurations (CBDCOM 1997). Appendix A also identifies the amounts of agent and energetics used in each weapon. Basic information on the various chemical agents and energetics used in ACW are presented in Sections 1.2.2.2 and 1.2.2.3, respectively. Appendix B contains a list of chemical agents and other chemicals regulated under the CWC.[6]

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[4] Leakers are munitions that leaked during storage and that have been subsequently overpacked.

[5] The unitary stockpile also contains TCs, spray tanks, and bombs in various types and sizes. These are considered types of containers, however, and are not included under the definition of ACW.

[6] In accordance with the CWC, destruction technologies must address Schedule 1 and 2 chemicals.

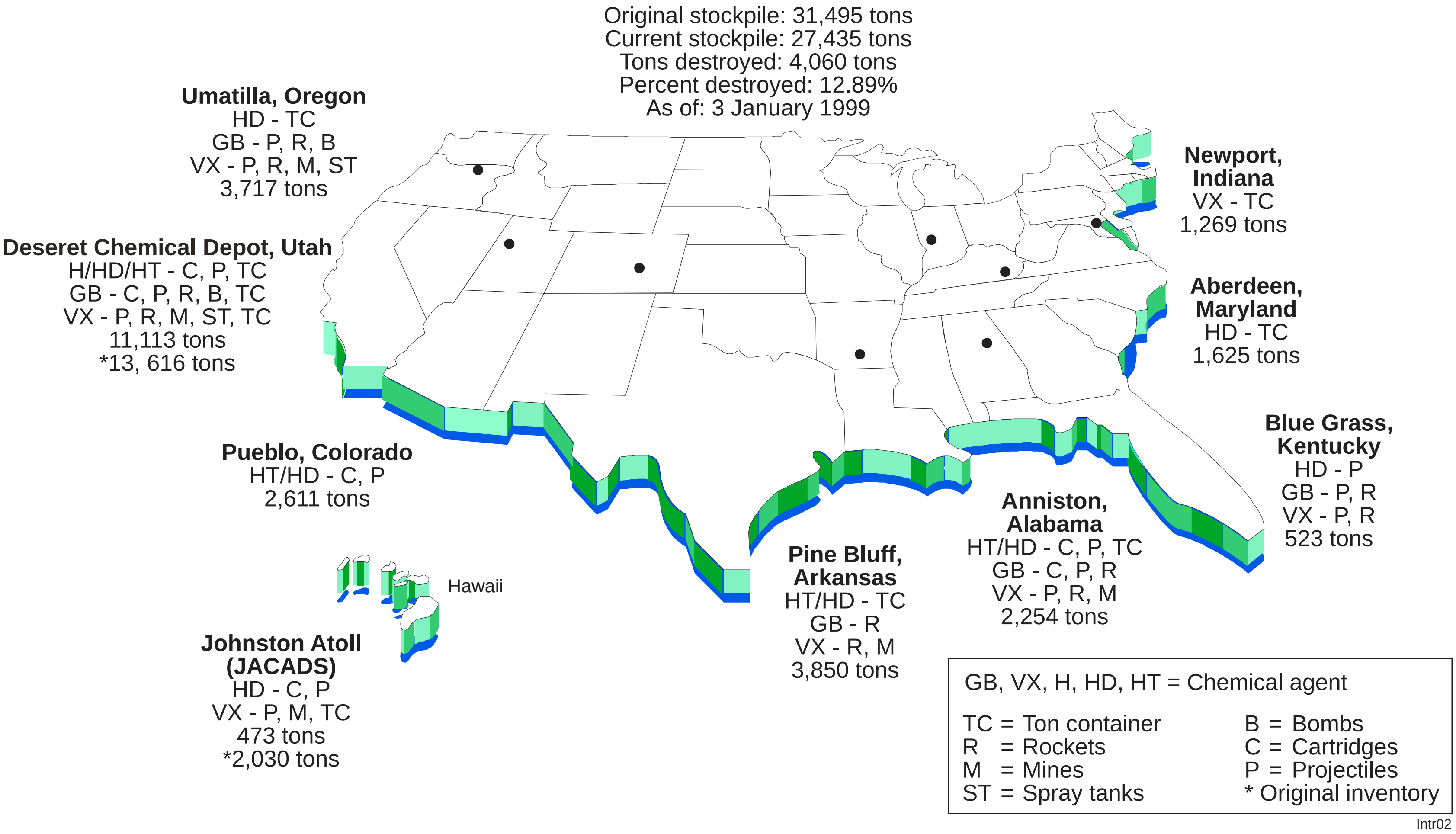

FIGURE 1.2 Types of Agent, Quantities of Agent, Types of Munitions, and Percentage of Total Agent Stockpiled at Each Storage Site (Source: Pacoraro 1999, as cited in NRC 1999) (Note: The information presented in this figure represents the stockpile as of January 3, 1999. Since that time, destruction of the inventory at JACADS has been completed, and much of the inventory at Deseret Chemical Depot has been destroyed.)

TABLE 1.1 Chemical Munitions Inventory by Stockpile Location[a,b]

		Anniston Army Depot		Deseret Chemical Depot	
Agent	Item	No. of Munitions	Agent (lb)	No. of Munitions	Agent (lb)
H	155-mm projectiles	c		54,663	639,540
HT	4.2-in. cartridges	183,552	1,064,600	62,590	363,020
HD	4.2-in. cartridges	75,360	452,160	976	5,860
HD	105-mm cartridges	23,064	68,500		
HD	155-mm projectiles	17,643	206,420		
GB	105-mm cartridges	74,014	120,640	119,400	194,620
GB	105-mm projectiles	26	40	679,303	1,107,260
GB	155-mm projectiles	9,600	62,400	89,141	579,420
GB	8-in. projectiles	16,026	232,380		
GB	M55 rockets	42,738	457,300	28,945	309,720
GB	M56 rocket warheads	24	260	1,056	11,300
VX	155-mm projectiles	139,581	837,480	53,216	319,300
VX	8-in. projectiles			1	20
VX	M55 rockets	35,636	356,360	3,966	39,660
VX	M56 rocket warheads	26	260	3,560	35,600
VX	Mines	44,131	463,380	22,690	238,240
L	Ton containers			10	25,920
HD	Ton container	108	185,080	6,398	11,383,420
HT	Ton container				
GA	Ton containers			2	2,820
TGA[d]	Ton containers			2	1,280
TGB[d]	Ton containers			7	6,960
GB	WETEYE bombs			888	308,140
GB	500-lb bombs				
GB	750-lb bombs			4,463	981,860
GB	Ton containers			5,709	8,598,200
VX	Spray tanks			862	1,168,880

TABLE 1.1 (Cont.)

		Blue Grass Army Depot		Pine Bluff Arsenal	
Agent	Item	No. of Munitions	Agent (lb)	No. of Munitions	Agent (lb)
H	155-mm projectiles				
HT	4.2-in. cartridges				
HD	4.2-in. cartridges				
HD	105-mm cartridges				
HD	155-mm projectiles	15,492	181,260		
GB	105-mm cartridges				
GB	105-mm projectiles				
GB	155-mm projectiles				
GB	8-in. projectiles	3,977	57,660		
GB	M55 rockets	51,716	553,360	90,231	965,480
GB	M56 rocket warheads	24	260	178	1,900
VX	155-mm projectiles	12,816	76,900		
VX	8-in. projectiles				
VX	M55 rockets	17,733	177,340	19,582	195,820
VX	M56 rocket warheads	6	60	26	260
VX	Mines			9,378	98,460
L	Ton containers				
HD	Ton container			107	188,400
HT	Ton container			3,591	6,249,100
GA	Ton containers				
TGA	Ton containers				
TGB	Ton containers				
GB	WETEYE bombs				
GB	500-lb bombs				
GB	750-lb bombs				
GB	Ton containers				
VX	Spray tanks				

TABLE 1.1 (Cont.)

		Pueblo Chemical Depot		Umatilla Chemical Depot	
Agent	Item	No. of Munitions	Agent (lb)	No. of Munitions	Agent (lb)
H	155-mm projectiles				
HT	4.2-in. cartridges	20,384	118,220		
HD	4.2-in. cartridges	76,722	460,340		
HD	105-mm cartridges	383,418	1,138,760		
HD	155-mm projectiles	299,554	3,504,780		
GB	105-mm cartridges				
GB	105-mm projectiles				
GB	155-mm projectiles			47,406	308,140
GB	8-in. projectiles			14,246	206,560
GB	M55 rockets			91,375	977,720
GB	M56 rocket warheads			67	720
VX	155-mm projectiles			32,313	193,880
VX	8-in. projectiles			3,752	54,400
VX	M55 rockets			14,513	145,140
VX	M56 rocket warheads			6	60
VX	Mines			11,685	122,700
L	Ton containers				
HD	Ton container			2,635	4,679,040
HT	Ton container				
GA	Ton containers				
TGA	Ton containers				
TGB	Ton containers				
GB	WETEYE bombs				
GB	500-lb bombs			27	2,960
GB	750-lb bombs			2,418	531,960
GB	Ton containers				
VX	Spray tanks			156	211,540

[a] Information on items appearing below the dashed line (including ton containers, bombs, and spray tanks) is provided for information purposes only. Although considered part of the inventory stockpile, these items are not ACW.

[b] The chemical munitions inventory located at JACADS was not included because destruction of this inventory has been completed.

[c] A blank indicates that the item is not included in the inventory at that location.

[d] The "T" before GA and GB stands for "thickened."

Appendix C provides physiochemical and toxicity information on the various agents, and Appendix D provides the same information on energetic materials used in ACW.

1.2.2.1.1 Projectiles and Mortars

Projectiles are fired from field artillery, including guns and cannons. Cartridges are fired from 4.2-in. mortars. Mortars are muzzle-loaded and used for shorter distances, whereas field artillery is breech-loaded and typically used for longer ranges. Projectiles and mortars are similar in design and construction. Basically, projectiles and mortars are hollow, steel cylindrical tubes with a tapered nose. A burster tube, which runs down the middle of the cylindrical tube, holds a high-explosive[7] charge known as a burster that disperses the chemical agent once detonated. The chemical agent is liquid at ambient temperature and pressure. The burster tube is typically made of steel. Some projectiles may be configured with propellant. The liquid chemical agent is held in the hollow spaces between the burster well and the wall of the shell. The nose of the shell contains the fuze. Not all projectiles and mortars are configured with a fuze. Lighter projectiles (105-mm projectiles and 4.2-in. mortars) can be manually lifted, while heavier projectiles (155-mm and 8-in.) have lifting plugs to assist in handling. The various types of projectiles and mortars are described below.[8]

155-mm Projectiles (artillery shells) – There are five different types of 155-mm projectiles in the unitary stockpile: the M121, M121A1, M104, M110, and M122. They differ in a variety of ways, including (1) agent type and amount and (2) energetic material type and amount. Each of these types of projectiles is 155 mm (6.1 in.) in diameter (nominal) and has a mass ranging from 93 to 99 lb (42 to 45 kg). They may contain any of the chemical agents GB, VX, H, or HD. The type of burster material also varies and may contain Composition B4 or tetrytol. In addition, some types of 155-mm projectiles (M121A1) may contain a supplemental charge (trinitrotoluene [TNT]). Some 155-mm projectiles may also be stored without a burster. The burster used for the mustard agent rounds is smaller than that used for the nerve agent rounds. A smaller burster charge is used for mustard agent rounds because HD has a tendency to burn rather than disperse if the burster charge is too strong. The 155-mm projectiles are typically stored on wooden pallets, with eight shells per pallet.

105-mm Projectiles (artillery shells) – There are two different types of 105-mm projectiles in the unitary stockpile: the M60 and M360. The M60 contains HD with a tetrytol burster, and the M360 contains GB and either a tetrytol or a Composition B4 burster. A smaller

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[7] A high explosive is characterized by the extreme rapidity with which its decomposition occurs; this action is known as detonation. When initiated by a blow or shock, decomposition occurs almost instantaneously, either in a manner similar to extremely rapid combustion or with rupture and rearrangement of the molecules themselves.

[8] Mortars may be identified as cartridges or projectiles. A cartridge is a projectile that has the propellant (if any) installed or packaged with it. Most projectiles have only the burster installed.

burster charge is used for the M60 because HD has a tendency to burn rather than disperse if the burster charge is too strong. Each of these types of projectiles is 105 mm (4.1 in.) in diameter (nominal) and has a mass ranging from 35 to 40 lb (16 to 18 kg). The M60 and M360 cartridges are stored with their cartridge cases and propelling charger (M67) in a wooden field box. They may or may not be stored with fuzes installed. The M60 and M360 shells are typically stored on wooden pallets, with 24 shells per pallet.

8-in. Projectiles (artillery shells) – The 8-in. projectiles, designated M426, contain either GB or VX. They are stored without fuzes but may be stored with or without bursters. If used, the burster is Composition B4, and a supplementary charge (TNT) is used. They have a mass exceeding 198 lb (90 kg) and are typically stored on wooden pallets, with six shells per pallet.

4.2-in. Mortars – There are two types of 4.2-in. mortar shells: M2 and M2A1. The basic difference is that the M2 mortar contains either HD or HT, while the M2A1 mortar contains only HD. There are minor differences in design as well (see Appendix A). Mortars contain a burster explosive composed of tetryl or tetrytol and are stored with fuzes and bursters in place. The M2 and M2A1 mortars are also sometimes configured with M6 propellant. Both types of mortars have a mass of 25 lb (11 kg). Mortars are similar to 105-mm projectiles, except that the outer shell of mortars is thinner, and there are internal vanes in the agent cavity. Mortars are stored with the burster, fuze, and propellant (if any) in fiber tubes. Typically, two mortar tubes are stored in a wooden field box, with either 36 boxes stored on a wooden pallet or 24 boxes stored on a wooden skid base.

1.2.2.1.2 M55 Rockets

M55 rockets are airborne weapons propelled by M28 propellant, which is a fuel and oxidizer mixture that powers the rocket. The M55 is the only rocket in the unitary chemical stockpile and contains either GB or VX. It is 115 mm (4.5 in.) in diameter (nominal) and 6.5 ft (2 m) long, weighs approximately 57 lb (26 kg), and is equipped with one fuze and two bursters.[9] The burster used is either Composition B or tetrytol. The rocket casing (containing the agent) is made of aluminum. Corrosion in some of the rockets has caused a leakage problem. M55 rockets are individually packed in fiberglass shipping/firing tubes with aluminum end caps. The tube is reinforced with resin and may also contain polychlorinated biphenyls (PCBs). An indexing ring is placed on the outside of the tube near the front (fuze) end of the rocket to permit easy identification of the front end of the rocket. The rockets are typically stored on wooden pallets, with 15 fiberglass tubes per pallet.

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[9] The M55 rocket consists of both the M56 warhead and a M67 rocket motor. The M56 warhead is essentially an M55 rocket without the rocket motor. Rockets may be stored without rocket motors.

PCBs are present in the M55 rocket tubes in varying concentrations, according to the specific lot. M55 shipping and firing tubes are believed to average 2,700 ppm PCB (EPA 1998). The firing tubes used in the actual DCD trail burn averaged 1,247 ppm. The weight of each tube is approximately 14 pounds. Waste materials containing PCBs in excess of 50 ppm are subject to regulation under the Toxic Substances Control Act.

1.2.2.1.3 M23 Land Mines

The chemical stockpile contains only one type of land mine, the M23. These land mines are filled with VX. The mines are 13 in. (33 cm) in diameter and 15 in. (3 cm) in height and weigh 23 lb (10 kg) without the fuze. Each mine contains several energetic components, including a conical burster that consists of Composition B4, a tubular mine activator (also called the initiator) that contains Composition B4, a cylindrical booster that contains Composition A5, and a small booster pellet containing tetryl. Land mines are stored in steel drums, with three in each drum. Activators and fuzes are packaged separately in the same drum. Typically, wooden pallets are used to store the drums, with 12 drums per pallet.

1.2.2.2 Chemical Agents

The principal unitary chemical agents in the U.S. ACW stockpile are the two nerve agents GB and VX and three related forms of sulfur mustard blister agents (H, HD, and HT). The chemical names for these agents are as follows:

GB - O-isopropyl methylphosphonofluoridate,

VX - O-ethyl S-(2-diisopropylaminoethyl) methylphosphonothioate,

H/HD - bis(2-chloroethyl) sulfide,[10]

T - bis(2-chloroethylthioethyl) ether, also known as T-mustard,[11] and

HT - a 60:40 combination of H/HD mustard and T-mustard.

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[10] HD is the distilled form of H. Also known as mustard gas, sulfur mustard, or yperite. ACW contain H or HD but not both.

[11] T is a component of HT and is not found in the unitary stockpile as T.

Although these agents are sometimes referred to as gases (e.g., mustard gas), they are liquids at ambient temperature and pressure. The agent formulations may contain thickeners and impurities and may also degrade into other chemicals during long-term storage. In addition, these agents, and especially mustard, may form a solid or semisolid "heel" under conditions of long-term storage.

GB is a liquid that is otherwise known as sarin. With a volatility similar to water, GB evaporates and dissipates relatively quickly. VX is a nonvolatile liquid with a high boiling point that may take days or weeks to evaporate and dissipate. In pure form, these agents are practically colorless and odorless. GB is relatively nonpersistent in the environment, whereas VX is considerably more persistent but will nevertheless degrade and dissipate in the environment over days or weeks. GB and VX are highly toxic nerve agents and are lethal in both liquid and vapor forms. They can kill their intended target in a matter of minutes and work by interfering with respiratory and nervous system functions.

Mustard agents have a characteristic garlic-like odor. Known as vesicant or blister agents in either vapor or liquid form, these chemicals cause severe disruption of the skin and other tissues. They may be lethal; however, the lethal dosage is considerably larger because their mode of action is longer than that of nerve agents. Mustard agent is practically insoluble in water, but once dissolved, it breaks down rapidly (via hydrolysis). As a result, mustard agent present in the environment in bulk amounts may persist for long periods; dispersed mustard agent or mustard agent released in vapor form may persist for only a short period.

Appendix C provides detailed information on these chemicals. As indicated previously, various impurities and degradation products may also be present along with the chemical agent. Section J.2 of CBDCOM (1997) contains a list of impurities that may be present.

ACWA technologies must address Schedule 1 and Schedule 2 compounds as identified by the CWC. Schedule 1 compounds consist of the agents themselves. Schedule 2 compounds include some toxic chemical agents but consist mostly of agent precursors (components used to create the toxic chemical agent). Nonagent Schedule 2 compounds are not controlled for their toxic properties. Rather, their distribution in commerce is restricted under the terms of the CWC because they may be used as precursors. Schedule 1 and 2 compounds are identified in Appendix B.

1.2.2.3 Energetics

As indicated in Section 1.2.2.1, a number of different types of energetic compounds are used for different purposes in ACW. The major energetics used in ACW are described below. Appendix A provides additional information on the amount of energetic material used in ACW. Appendix D provides physiochemical and toxicity information on energetic chemicals. Unless otherwise specified, the following information is obtained from Section J.2 of CBDCOM (1997).

Tetryl – The chemical name for tetryl is trinitrophenylmethylnitramine. Tetryl is also known as N-methyl-N,2,4,6-tetranitrobenzamine. Tetryl is a high explosive used for burster material for mortars. It is also used as a booster in M23 land mines. Tetryl is used in combination with TNT to make up tetrytol, which is used as a burster material for various types of projectiles.

TNT – The chemical name for TNT is 2,4,6-trinitrotoluene. TNT is a high explosive used in burster material (a component of tetrytol, Composition B, and Composition B4) and is also used as a supplementary charge material in several types of projectiles.

Nitrocellulose – Nitrocellulose, also known as cellulose nitrate, is a flammable liquid or semisolid material of variable composition that is a component of propellants. It is a major component of M28 propellant, used in M55 rockets; M1 propellant, used in the 105-mm projectile; and M6 propellant used in some mortars.

Nitroglycerin – The chemical name for nitroglycerin is 1,2,3-propanetriol trinitrate. Nitroglycerin is a highly reactive chemical used in making explosives and propellants. It is often combined with nitrocellulose as a double-base propellant. Nitroglycerine is a major component of M28 propellant used in M55 rockets, as well as of the M6 propellant used in some mortars.

RDX – The chemical name for RDX is 1,3,5-triaza-1,3,5-trinitrocyclohexane. It is a high explosive used in combination with other chemicals (Composition B and Composition B4) as burster material.

Tetrytol – Tetrytol is a combination of tetryl and TNT, in a 70%/30% mixture. It is a high explosive used in burster material in projectiles, mortars, and land mines.

Composition B[12] – Composition B (also known as Comp B) is a combination of RDX, TNT, and wax in a 60%, 39%, 1% mixture. It is used as a burster material in the M55 rocket.

Composition B4 – Composition B4 (also known as Comp B4) is a combination of RDX, TNT, and calcium silicate in a 60%, 39.5%, 0.5% mixture. It is used as a burster material in several types of projectiles and also in the M23 land mine.

Composition A5 – Composition A5 (also known as Comp A5) consists of RDX and stearic acid. Type 1 Composition A5 is approximately 98.5% RDX and 1.5% stearic acid; Type II Composition A5 is approximately 98% RDX and 1.6% stearic acid, with 0.4% lubricant (U.S. Army 1990a). The stearic acid is used as a desensitizer. Composition A5 is a booster material used in the M23 land mine.

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[12] Compositions are explosives in which two or more explosive compounds are mixed to produce an explosive with more suitable characteristics for a particular application (U.S. Army 1990a).

M1 Propellant[13] – M1 is a propellant used in 105-mm projectiles. Its nominal composition is 84% nitrocellulose, 9% dinitrotoluene, 5% dibutylphthalate, 1% diphenylamine, and 1% lead carbonate.

M6 Propellant – M6 is a single-base propellant that is used with the M2 and M2A1 4.2-in. mortars. M6 propellant is composed of 87% nitrocellulose, 10% dinitrotolune, 3% dibutylphthalate, and a small amount (<1%) of residual ethyl alcohol and water (U.S. Army 1990a).

M28 Propellant – M28 is a double-base propellant nominally composed of 60% nitrocellulose, 23.8% nitroglycerine, 9.9% triacetin, 2.6% dimethylphthalate, 2.0% lead stearate, and 1.7% 2-nitrodiphenylamine. It is used in M55 rockets.

Fuze Material – Fuzes contain energetics that initiate the rest of the explosive train (i.e., supplementary charges and bursters). The primary component of most fuzes used in ACW is lead azide. Other components of fuze materials may include RDX, black powder, lead styphenate, barium nitrate, tetracene, potassium chlorate, antimony sulfide, carborundum, lead thiocyanate, and other compounds. Some fuze materials are designated as high explosives because of their ability to detonate.

Additional information on military explosives can be found in U.S. Army (1990a). In addition, as with the chemical agents, energetic materials may contain small amounts of impurities.

1.2.2.4 Other Components

Shell casing materials, as well as crates, packing boxes, and other materials used for shipping and storage, are also included under the ACWA umbrella as a category of materials that ACWA technology systems must address. Metal components are typically decontaminated so that there is no residual agent; this is referred to as a 5X (XXXXX) condition. Materials decontaminated to a 5X condition may be released for unrestricted use (e.g., recycling). Nonmetallic materials are typically included under the category of waste called dunnage. In most cases, materials classified as dunnage will not be contaminated with agent or energetics; however, there may be instances in which these materials could be contaminated. Because of this possibility, ACWA technology systems must be capable of addressing these materials. The U.S. Army's system for decontaminating chemical agents is described below.

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[13] When ignited, propellants produce large quantities of hot gaseous products. Complete combustion or deflagration occurs in milliseconds, and the pressure produced accelerates the projectile toward its target. The main ingredients in most propellants are nitrocellulose, nitroglycerin, and nitroguanidine (U.S. Army 1990a).

The U.S. Army's system for decontaminating chemical agents (3X/5X system) was established for decontaminating material suspected of being contaminated with chemical agents so as to strictly minimize the possibility for external release of even the smallest quantities of chemical agent (U.S. Army 1997). Under the system, material potentially contaminated with chemical agents must be decontaminated thoroughly (according to documented, locally approved procedures) and then checked for the possible emission of agent vapors.[14] If the concentrations of agent in the surrounding air space following treatment are found to be below specified limits (i.e., worker 8-hour time-weighted averaged airborne exposure limits [AELs]), the material is declared to be 3X, implying acceptable surface decontamination. Department of the Army (DA) Pamphlet 40-8 (U.S. Army 1990b) and DA Pamphlet 40-173 (U.S. Army 1991) specifically describe the AELs.

Workers are allowed to approach and handle 3X items with only a minimum of precautions. Such material or items are safe from the standpoint of both physical contact and close association. This 3X requirement ensures the safe disposition of waste material in a disposal facility that is permitted under Subtitle C of the Resource Conservation and Recovery Act (RCRA) to receive hazardous wastes and is in full compliance with applicable federal, state, and local environmental regulations.[15] The 3X requirements also specify packaging, tracking, and disposal requirements that are designed to protect public health. The U.S. Army considers it important to closely track the history and disposition of material in the classification system. Strict labeling and record-keeping requirements are specified in the U.S. Army regulation, as are the analytical procedures to be used and their associated quality control and quality assurance procedures.

The U.S. Army does not consider 3X material to be completely agent-free or completely risk-free. Such descriptions are reserved for 5X material, which may be released from U.S. Army control provided that such release is in accordance with all applicable federal, state, and local regulations. To be considered 5X, an item must either be heated to 1,000EF (538EC) for a minimum of 15 minutes (a treatment considered to be sufficiently severe to destroy all agent molecules) or be treated in a manner capable of such extensive agent destruction that the total quantity of agent can be shown to be below a level determined by the U.S. Army Surgeon General to represent no adverse health effects. For any alternative treatment to be used, the procedures and analyses must be submitted and approved through the appropriate headquarters organizational structure.

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[14] The headspace around the material is sealed to the extent possible and allowed to reach thermal equilibrium.

[15] The U.S. Army requires 3X material to remain under government control; hazardous waste disposal facilities permitted under RCRA are considered to meet that requirement.

1.2.3 STORAGE OF ACW

ACW storage configurations; maintenance, handling, and inspection; and handling of leaking munitions are discussed in this subsection. Storage is a common element of all destruction technologies because some period of storage would be required while pilot testing of the technologies is planned and implemented.

1.2.3.1 Storage Configurations

All chemical agents and munitions are maintained within a chemical storage area at which extensive security precautions are taken to control entry. All the munitions in the inventory are stored inside concrete-walled, earth-covered structures, commonly called igloos. A typical storage configuration is described below.

The storage igloos are designed to protect the munitions from blast and shrapnel if weapons in a neighboring igloo were to detonate. The igloos are typically constructed of reinforced concrete and have steel or concrete/steel doors. A lightning protection system is provided. The igloo floors can be decontaminated in the event of a spill or leak. Passive ventilation is in place in the form of both louvered vents in the front concrete face or in the door, as well as a single ventilation stack penetrating the earthen cover at the rear of the igloos. Fusible links in the vents close the ventilation path in the event of a fire. The igloo is designed to prevent water entry. A reinforced concrete "King Tut" block in front of each door acts as a security device. This block weighs approximately 5,000 lb (2,300 kg) and rests on a post embedded in a concrete pad (the "apron") in front of each igloo. A forklift is required to remove the block from the igloo door. The doors are padlocked shut whenever access is prohibited, and each igloo has an intrusion detection system. No electrical power is installed permanently inside the igloo. However, there is an electrical junction box on the outside front face of each igloo.

The chemical munitions are stored in boxes (cartridges) and on pallets (shells, rockets, and land mines). Aisles between the boxes and pallets are maintained so that units in each stack can be inspected, inventoried, and removed for shipment, maintenance, or demilitarization, as appropriate. Figures 1.3 through 1.5 show a typical storage configuration for the 155-mm projectiles. Similar configurations are used to store 105-mm projectiles and 4.2-in. mortars.

1.2.3.2 Handling and Inspection

Routine activities associated with ACW storage consist of periodic inspection, surveillance, and inventory of the containers as well as the storage facilities. When inspected, both the containers and the storage area are visually examined, and the air is monitored for the presence of agent.

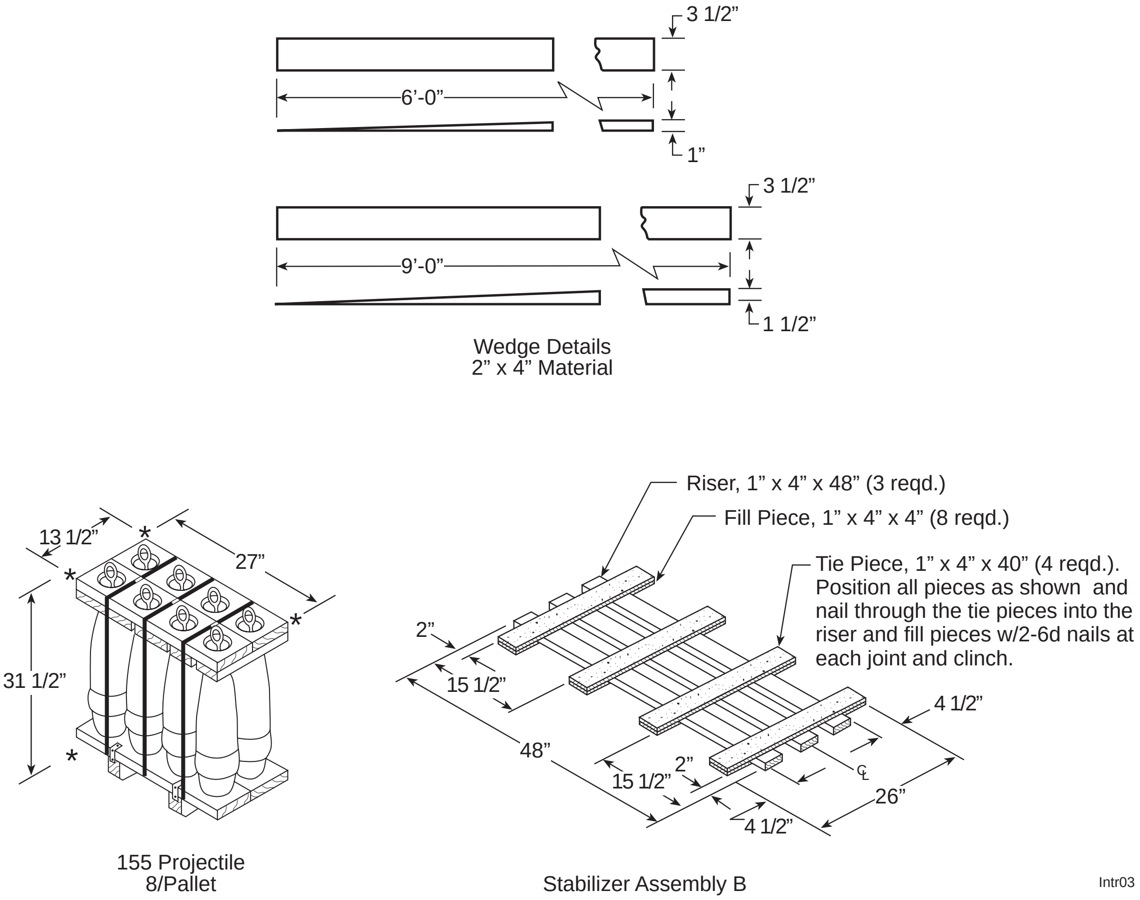


FIGURE 1.3 155-mm Projectile Storage Configuration: Sheet 1

The U.S. Army Soldier and Biological Chemical Command (SBCCOM, formerly CBDCOM) oversees storage and surveillance of chemical munitions. This activity consists of maintaining measures necessary (1) to ensure availability of a chemical deterrent for national defense, while demilitarization in accordance with the CWC is carried out, and (2) to ensure continued safety in storage.

1.2.3.3 Leaking Munitions

Small quantities of the stored munitions may leak. When agent is detected in a storage location, special procedures are followed. These procedures involve (1) identifying the specific munition that is leaking; (2) removing the munition from storage; and (3) simultaneously decontaminating the individual munition, adjacent munitions, and other contaminated areas.

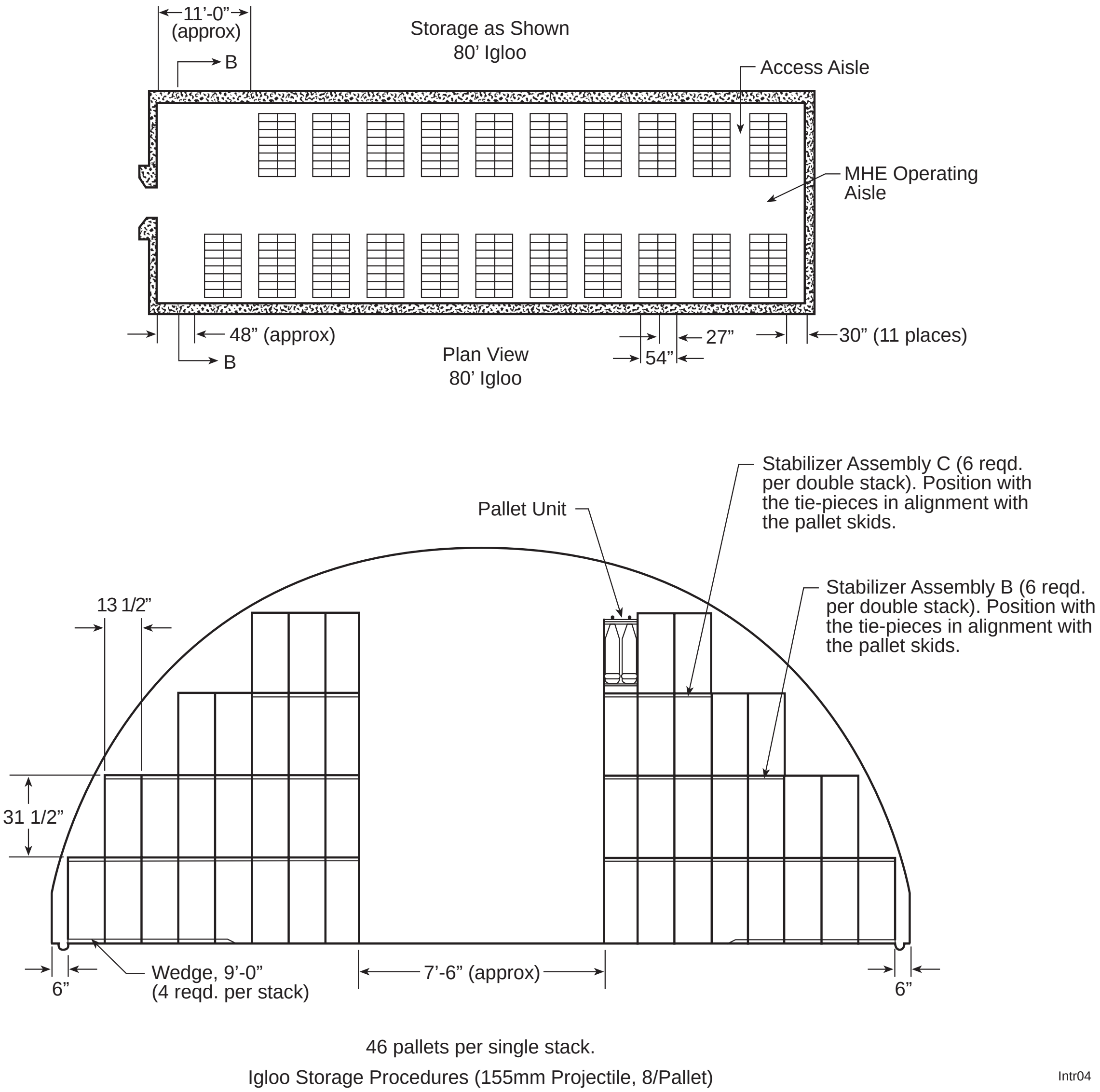
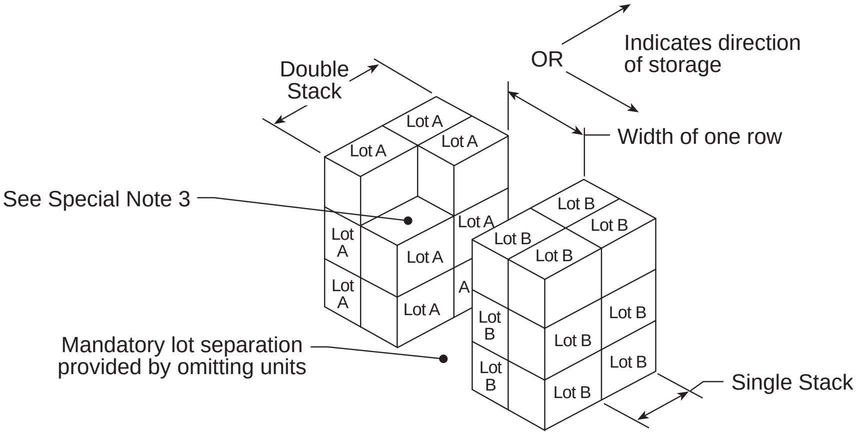


FIGURE 1.4 155-mm Projectile Storage Configuration: Sheet 2

The leaking munition is placed in a barrier bag (a plastic wrap) that provides immediate agent containment. The wrapped munition is then placed in a munition-specific steel overpack container designed to provide a high level of assurance of liquid agent and vapor containment, even if the munition were to continue to leak. Known leaking munitions are placed in secure containers and stored as hazardous waste in separate RCRA-permitted igloos.

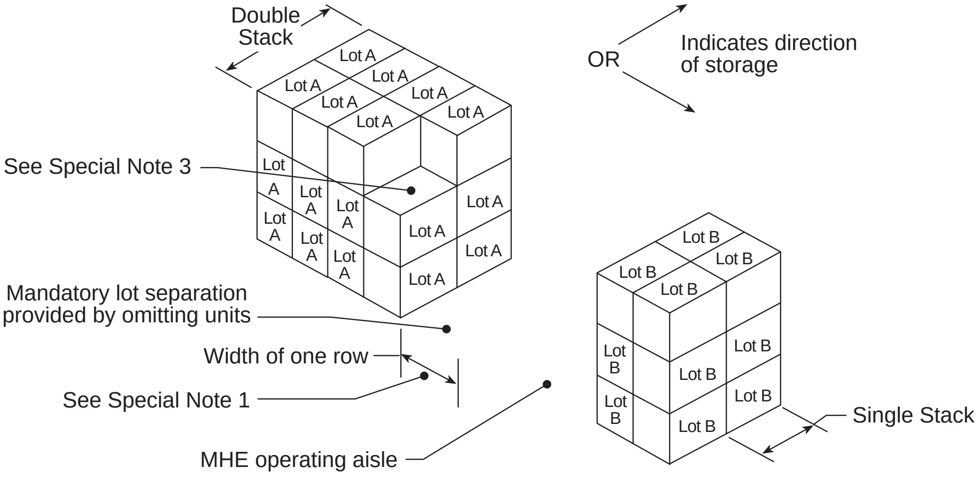
Leaking munitions are part of the U.S. stockpile and are to be addressed as part of the ACWA program. Baseline or ACWA technologies will be used to destroy leaking chemical munitions, although different munitions access procedures will be followed to ensure the safety of the demilitarization workforce.



Typical Lot Separation Detail 1
(Stradley and/or oval-arch stack depicted)

Special Notes

1. Lot separation will be maintained within a storage magazine. The typical details on this page illustrate possible configurations which comply with the mandatory lot separation requirements. Other configurations may also be used, provided the other configurations comply with the basic requirements stated herein.
2. When storing multiple lots within a magazine, different lots will be separated within a double stack by omitting units in the manner shown in the “Typical Lot Separation Details”.
3. One lot will not be stacked on top of another lot.
4. To satisfy lot quantities, it may be necessary to omit a row which would normally be next to an operating aisle, since it is not permissable to stack items of one lot immediately adjacent to items of another lot within the same single stack.



Typical Lot Separation Detail 2
(Stradley and/or oval-arch stack depicted)

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FIGURE 1.5 155-mm Projectile Storage Configuration: Sheet 3

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1.3 OVERVIEW OF ACWA TECHNOLOGY SELECTION PROCESS

The ACWA technology systems were evaluated for potential pilot-scale testing on the basis of a three-phase process: Phase I, Criteria Development; Phase II, Technology Assessment; and Phase III, Demonstration. After screening, seven technology systems were originally selected for consideration. The three phases of the selection process and the corresponding selection criteria are summarized below. Figure 1.6 provides an overview of the technology assessment (Phase II).

In Phase I, criteria were developed by the PMACWA and the Dialogue[16] for evaluating technology systems for selection for demonstration and for the evaluation of demonstration results. The Go/No-Go Screening Criteria provided an initial screening of proposals, and the Demonstration Selection Criteria were used to select technology systems for demonstration testing. The Demonstration Selection Criteria were then expanded into Program Implementation Criteria that were used to evaluate the technology systems following the completion of demonstration testing. All three sets of criteria were incorporated into the ACWA Request for Proposal (RFP) (CBDCOM 1997) and were reflected in the proposals received from industry.

The purpose of Phase II, Technology Assessment, was to select technology systems for Phase III, Demonstration Testing. Phase II was divided into the following four steps, as shown in Figure 1.6:

> *Step 1: Go/No-Go* – The Technology Proposals were assessed as to overall responsiveness and evaluated against the Go/No-Go Screening Criteria. As a result of the evaluation, a basic task-order contract was awarded to offerers determined to be responsive to the RFP requirements and whose technology met the Go/No-Go Screening Criteria. Seven technologies were selected from a total of 12.
>
> *Step 2: Initial Assessment/Data Gap Resolution* – The initial assessment of each technology against the Demonstration Selection Criteria identified data gaps in describing the technology or demonstration and targeted data gap resolution. The technologies for all technology providers receiving a task order contract were evaluated against the Demonstration Selection Criteria (CBDCOM 1997) to identify data or information missing from their proposals. The missing data and information were identified as data gaps. Data Gap Identification Reports (DGIRs) were provided to the technology providers.

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[16] The Dialogue refers to a public involvement process instituted by the PMACWA to involve citizen stakeholders in every aspect of the ACWA program, including the evaluation and selection of technology systems. Details on the Dialogue's involvement in the ACWA program may be found in Chapter 10 of NRC (1999) and in the PMACWA Reports to Congress (PMACWA 1997, 1998, 1999b, 2000b, 2001c).

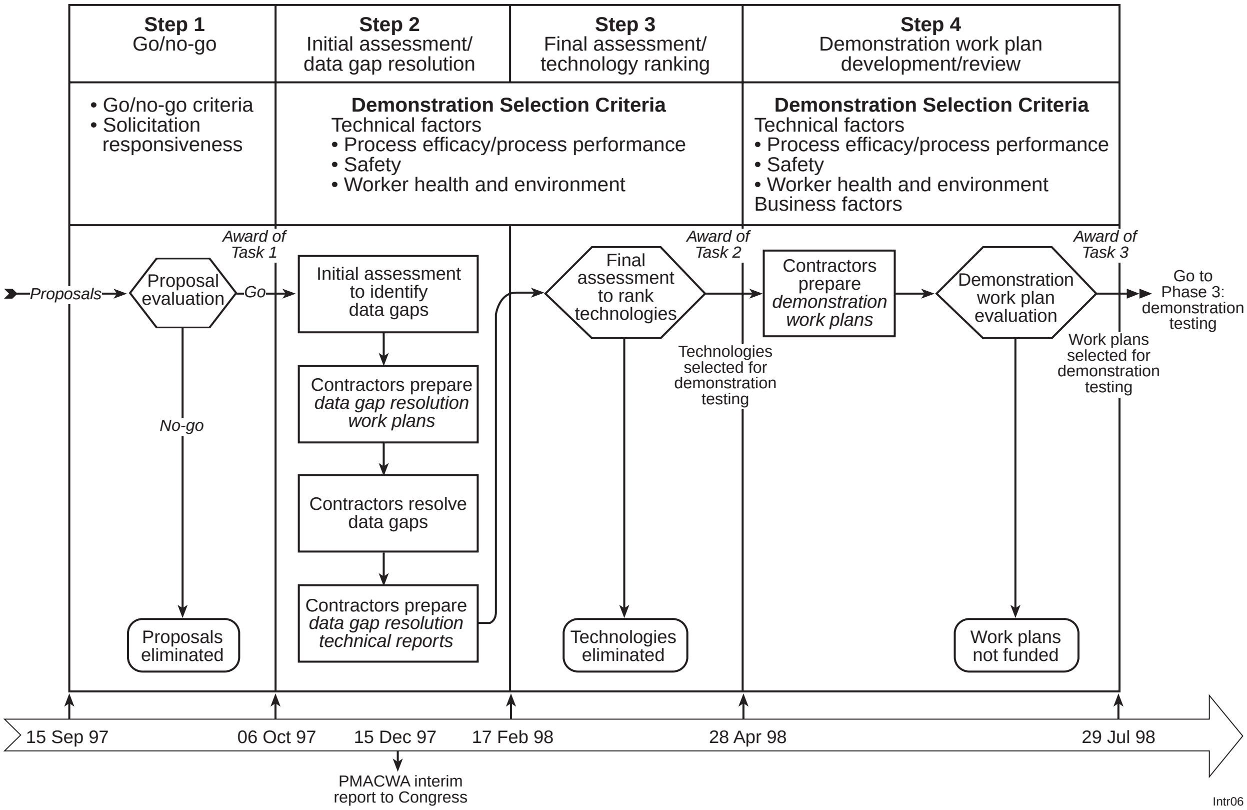

FIGURE 1.6 Four-Step ACWA Phase II Technology Assessment (Source: PMACWA 1999a)

Using the appropriate DGIRs, each contractor prepared a Data Gap Work Plan (DGWP) and submitted it to the government by December 10, 1997. The DGWP provided a detailed description of how the contractor would resolve the data gaps (including any testing) and included a milestone schedule for completion of the work. With the approval of the DGWP, the technology provider was authorized to proceed with the approach presented in the DGWP and to prepare the Data Gap Resolution Report (DGRR). This completed the initial assessment of the proposals.

Step 3: Final Assessment/Technology Ranking – A final assessment of each technology was conducted by comparing all provided information (Technology Proposal and DGRR) with the Demonstration Selection Criteria. The Dialogue participated throughout this process. Six technology systems were recommended for demonstration testing: AEA Technology, Burns and Roe, General Atomics, Lockheed Martin, Parsons/AlliedSignal, and Teledyne-Commodore. Each of these technology providers received a task order to prepare a Demonstration Work Plan.

Step 4: Demonstration Work Plan Development/Review – Each of the six technology providers that were awarded task orders prepared a detailed

Demonstration Work Plan that was evaluated against the full set of Demonstration Selection Criteria: technical factors (process efficacy, worker health and safety, human health and environment) and business factors. In addition to the likelihood of conducting a successful demonstration on the basis of the evaluation, the constraint of program resources also was used to determine which technologies continued into the demonstration phase. A Best Value Decision was made to determine the appropriate technologies to demonstrate. The decision was based on the technical merit of each proposed technology and on resource considerations, such as cost and availability of facilities.

As a result of the selection process, six of these technology systems were selected for demonstration testing. Demonstration testing was conducted in two phases:

- Demonstration testing in Phase I (Demo I) initially involved three of the six technology systems; however, only two technologies were taken to advanced stages of testing. Demo I was initiated in February 1999 and completed in April 1999.

- Demonstration testing in Phase II (Demo II) included three additional technology systems. Demo II was initiated in June 2000. Two of these technology systems advanced and were completed in September 2000.

Following demonstration, EDSs were initiated for the technology systems. These studies, which are considered part of the demonstration phase, were devised to yield additional data, as needed, to design a full-scale pilot facility and to develop life-cycle cost and schedule estimates. While EDSs have been completed for the Demo I technologies, EDSs for the Demo II technologies have not been completed. Therefore, this TRD presents information on each technology as of the completion of demonstration testing.

Demo I testing was conducted in spring 1999, and Demo II testing was conducted in summer 2000. Demo I testing results are provided in PMACWA (1999a); Demo II testing results are provided in PMACWA (2001b). The PMACWA has determined that four of these technology systems are acceptable for use in destroying ACW: two technology systems demonstrated during Demo I and two technology systems demonstrated during Demo II. The systems are as follows:

- Demo I

    - Neutralization/Solid Wall-Supercritical Water Oxidation

    - Neutralization/Biotreatment

- Demo II
  - Neutralization/Gas-Phase Chemical Reduction™/Transpiring Wall-Supercritical Water Oxidation
  - Electrochemical Oxidation

However, and as indicated previously, only the ACWA Demo I technologies are discussed for PCD. The National Defense Authorization Act for Fiscal Year 2001 (Public Law 106-398) specifically indicates that only ACWA technologies that were demonstrated on or before May 1, 2000, may be considered for PCD. This limitation effectively precludes consideration of the Demo II technologies for PCD.

While demonstration testing for the Demo I and Demo II technologies has been completed, EDSs are being implemented. The DOD determined that these studies were necessary in preparation for full-scale pilot design and permitting. While EDSs have been completed for the Demo I technologies, they have not been completed for the Demo II technologies. EDS testing results are not yet available from the PMACWA for either the Demo I or Demo II technology systems. Thus, this TRD presents information on each technology as of the completion of demonstration testing.

1.4 BASELINE AND ACWA SYSTEM TECHNOLOGIES

This section introduces the various technologies that may be used to access ACW and to treat the agent, energetics, metal parts, and dunnage, as well as the technologies for waste management and pollution control. It pertains to all ACW at all installations that are the focus of the EIS. Figure 1.7 provides an overview of the generalized treatment process for all technology systems that may be used to destroy ACW.

The ACW pilot facility may be designed, constructed, and operated by any number or combination of firms selected through a competitive process. However, on the basis of the requirement to use an ACWA-demonstrated technology, it is assumed that an ACWA pilot facility will be represented by the technologies assessed by the PMACWA (PMACWA 1997, 1998, 1999b, 2000b, 2001c). These technologies, as proposed by the ACWA technology providers, are used as models in this document to describe potential ACWA pilot facilities.

Although baseline incineration is not an ACWA technology system, each of the ACWA systems borrow one or more components from the baseline incineration process (e.g., reverse assembly, pollution abatement system). Therefore, review of the baseline incineration process is important for gaining a complete understanding of the ACWA systems. Incineration is not addressed as a candidate technology in the EIS that this resource document is intended to support.

1.4.1 MUNITIONS ACCESS TECHNOLOGIES

Munitions access technologies encompass those processes used to access agent and energetics from ACW and to prepare other ACW components, including metal parts and dunnage, for subsequent treatment.

1.4.1.1 Baseline Reverse Assembly

The baseline reverse assembly process is described in a number of references (MITRE 1993, PMCD 1997, SAIC 1996, NRC 1999). A detailed discussion is also provided in NRC (1999), which references the other documents.

Baseline reverse assembly refers to the process developed by the U.S. Army for disassembling ACW in preparation for incineration of the agent material and treatment of the energetics. Baseline reverse assembly was used at JACADS and is currently being used at TOCDF, with some modifications to the original process. Baseline reverse assembly is also being installed at UMDA, PBA, and ANAD. The general process, with some modifications, is

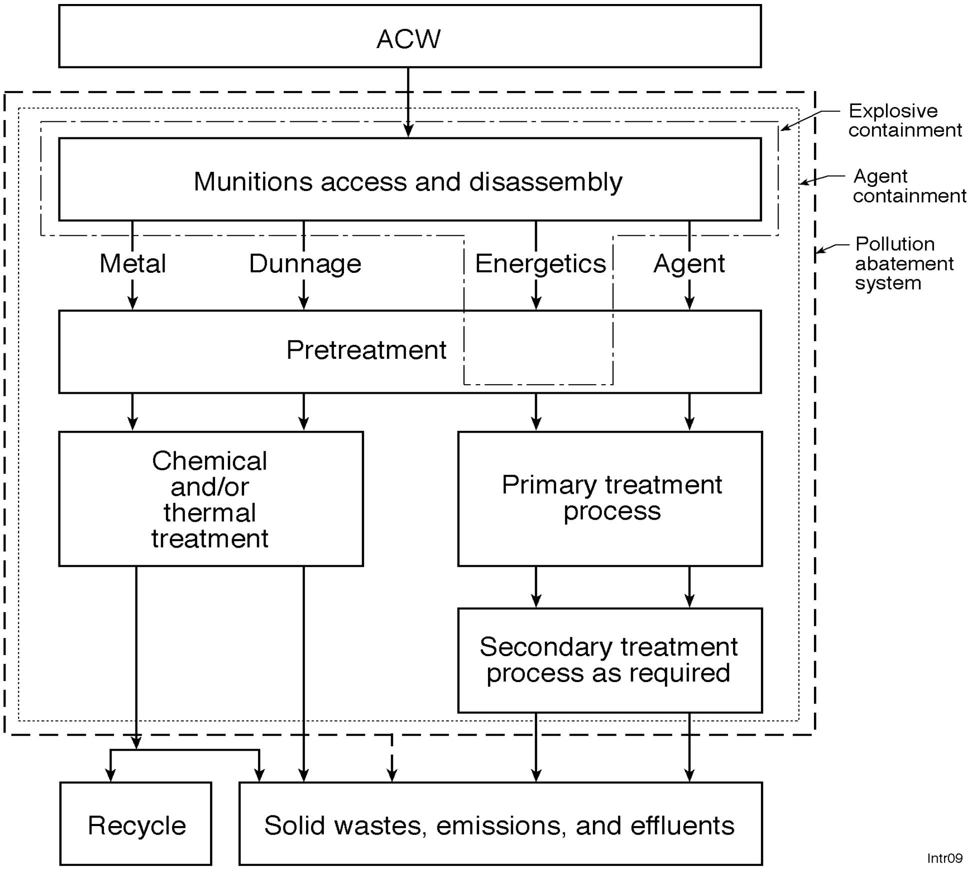

FIGURE 1.7 Generalized ACWA Treatment Process

used by all the ACWA technology systems. Thus, baseline reverse assembly is not specific to incineration. The process is referred to as reverse assembly because, with some exceptions (e.g., the M55 rockets), the process may be viewed as a reversal of the assembly process. In addition, the same general process, with modifications, is used for most leaking munitions and leakers.

Following the initial unpacking, the baseline reverse assembly process is automatic. Operators unpack the ACW and place them, one by one, on a conveyor system. Energetic components are removed from the munition items in an explosion-containment room (ECR). The munition is conveyed to another room, where liquid agent is then drained from or washed out of the agent cavity into storage vessels. Metal parts are conveyed to a metal parts furnace (MPF), and dunnage is conveyed to an incinerator.

1.4.1.2 Cryogenics

Cryofracture is a process developed by General Atomics (as part of the Cryofracture Incineration Demonstration Program) for the U.S. Army in which munitions are embrittled by cooling in liquid nitrogen at -200ºF (-128ºC) and then fractured to access the chemical fill. The liquid nitrogen embrittles the munition casing, thus making the casing more amenable to fracture. In 1994, MITRE Corporation conducted an independent assessment of design verification tests performed by General Atomics (MITRE 1994). In addition, the cryofracture process is described in detail in several sources (NRC 1991, 1999; ANL 1998; General Atomics 1999).

The cryofracture process was developed for all ACW types but is applied to projectiles and mortars for the ACWA program. The process begins by using robots to access the projectiles and mortars from pallets. Explosives are removed from the munition item and processed separately. Rounds are either placed in the nitrogen bath separately or still packaged in their boxes. The munitions are then robotically removed from the bath, transferred to an ECR, and sheared or fractured using a hydraulic press to expose the chemical fill. Sheared or fractured munitions, agent, dunnage, and spent decontamination solutions are then further treated in separate systems.

Cryogenic cooling may also be used to embrittle polymers (e.g., protective suits) or other materials for size reduction (fragmentation) operations.

1.4.1.3 Fluid-Abrasive Cutting

Fluid-abrasive cutting (also referred to as fluid-jet cutting) has been proposed as an alternative for accessing munition components. Fluid-abrasive cutting usually employs a water fluid jet; however, other liquids (e.g., ammonia) have been demonstrated. The liquid is forced through a narrow opening under high pressure. Abrasives, such as sand or garnet, may be added to the fluid to enhance the cutting action, especially with friable materials (ANL 1998). Fluid-abrasive cutting may be used to access both agent and energetic components. A summary of the use of fluid-abrasive cutting is provided in NRC (1999).

1.4.1.4 Fluid-Mining

Fluid-mining is a process similar to fluid-jet cutting; water or other liquids are forced through a narrow opening under pressure and used as a pressure wash to remove or "mine" agent and/or energetics from munitions (ANL 1998). The technology uses a lower pressure and higher flow rate than abrasive cutting, as well as special nozzles. A summary of the use of fluid-mining is provided in NRC (1999).

A related form of fluid accessing is referred to as fluid-spray washing or just fluid washing. This technology was developed under the U.S. Army's Alternative Technology Program (ATP) for removing the heels from drained TCs. Fluid-spray washing uses lower pressures and flow rates than fluid-mining, but it still uses special nozzles to wash material from surfaces.

1.4.1.5 Dunnage Size Reduction

Most ACW destruction systems propose some means of reducing dunnage, including the pallets on which munitions are stored, used protective suits, and other materials, to a size appropriate for introduction into subsequent treatment systems. The primary means of reducing these materials to an appropriate size are technologies commonly used in normal industrial applications. The primary equipment consists of shredders, hammer mills, macerators, micronizers, and pulpers (NRC 1999). Shredders and hammer mills are part of the baseline process. Micronizers and pulpers (in addition to shredders and hammer mills) are proposed as part of some of the ACWA technology systems. Fluid-abrasive cutting and fluid-mining may also be used for dunnage size reduction, as well as simple guillotine shearing.

1.4.2 AGENT TREATMENT TECHNOLOGIES

1.4.2.1 Baseline Incineration (Liquid Incinerator)

As indicated previously, baseline incineration of chemical agents from assembled and bulk chemical munitions was the technology used at JACADs for destroying ACW. This technology is currently in place at TOCDF, and incineration systems are being constructed at PBA, UMDA, and ANAD. The technology used at these locations for agent incineration is a liquid incinerator (LIC). The LIC is used to destroy chemical agent as well as spent decontamination (neutralization) fluids generated elsewhere throughout the treatment facility. This technology was selected pursuant to the *Final Environmental Impact Statement for Baseline Incineration* (PMCD 1988). Original proof testing of the incineration technology was conducted at the U.S. Army's Chemical Agent Munitions Disposal System facility located at the DCD in Utah.[17] A review of the U.S. Army's experience in industrial-scale chemical agent/munitions disposal is provided in Chemical Material Destruction Agency (1993). Because baseline incineration is a primary treatment process that has been demonstrated to destroy chemical agents to a destruction removal efficiency of 99.9999% (PMCD 1996), no secondary treatment would be expected to be necessary following initial incineration (e.g., to remove Schedule 2 compounds).

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[17] DCD was formerly known as the Tooele Army Depot (TEAD).

1.4.2.2 Hydrolysis

The process of hydrolysis is used in several of the technologies developed under the ACWA program to neutralize chemical agents. For this application, hydrolysis and chemical neutralization[18] are synonymous. A neutralization process has been developed under the U.S. Army's ATP. While hydrolysis with either water or caustic (e.g., sodium hydroxide [NaOH]) can be used for the mustard agents, hydrolysis using solutions of NaOH is required for the nerve agents and also for energetics (discussed in Section 1.4.3). Hydrolysis involves the breakdown of the chemical in a reagent, typically water or caustic; the resulting product is called hydrolysate. Although hydrolysis is quite effective in breaking down the parent chemical agent molecule, it does not necessarily reduce all hazards. Hydrolysis breakdown products may be present in hydrolysate, including Schedule 2 compounds (e.g., thiodiglycol, a hydrolysis product of mustard). Other hydrolysis products include sodium chloride and other salts. Thus, while hydrolysis is a primary treatment technology used to destroy chemical agents, a secondary treatment process will be used to destroy hydrolysis breakdown products. Hydrolysis of agent compounds is discussed extensively in NRC (1999).

1.4.2.3 Supercritical Water Oxidation

Supercritical water oxidation (SCWO) is a secondary treatment process. It is a thermal oxidation process that mineralizes agent and energetic hydrolysates at temperatures and pressures above the critical point of water, which is 705ºF (374ºC) and 3,205 psia (22 MPa) (i.e., supercritical conditions). The supercritical phase is the point at which water is transformed from a liquid to a gas (or from a gas to a liquid). In the supercritical phase, water has enhanced solvent properties. Organic compounds contained in other materials become more soluble, and salts present in solution also are precipitated out at this point. SCWO is best suited for wastes that have a high water content and is applied as a secondary treatment process following hydrolysis or other primary treatment. After oxidation of the hydrolysate, the effluent is cooled, depressurized, and separated into gaseous, solid, and liquid streams. Salts and other insoluble materials are precipitated out.

SCWO is discussed extensively in NRC (1999). The SCWO technology is a component of the VX neutralization/mineralization process that will be pilot tested for bulk VX at Newport Chemical Depot (NCD) (PMCD 1998b).

SCWO is applied as part of two of the ACWA technology systems as a secondary treatment process for both agent and energetic hydrolysates. The processes used for agent and energetic hydrolysates are chemically identical.

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[18] Neutralization is sometimes referred to simply as "neut."

A solid-wall or transpiring-wall unit may be employed. A transpiring-wall SCWO, or TW-SCWO, differs from a solid-wall SCWO in that a barrier of clean water is dispersed from the sides of the TW-SCWO unit as a means of limiting corrosion and solids buildup (NRC 1999). The unit, called a transpiring platelet wall reactor, was developed and patented by GenCorp/Aerojet and Foster Wheeler (NRC 1999). In addition, whereas the solid-wall SCWO treats agent and energetics hydrolysates separately, the TW-SCWO treats a combined agent and energetics hydrolysate stream. Details of both the solid-wall and transpiring-wall units are provided in the installation-specific volumes of this TRD.

1.4.2.4 Biotreatment

Biotreatment is a secondary treatment process that can be used in conjunction with hydrolysis of chemical agent and energetics. Its objective is not to treat the agent, but to treat residuals (such as hydrolysate) from a primary treatment process. Biotreatment, also termed biological treatment or biodegradation, uses microbial organisms, primarily bacteria, to convert chemically complex organic compounds to simpler and less toxic materials. In the case of chemical agents, the goal would be to reduce the presence of Schedule 2 compounds to nondetectable levels.

The biotreatment process uses aerobic bacteria, oxygen, and various nutrients to convert the target chemicals to carbon dioxide (CO_2), water, nitrates, phosphates, and organic biomass. The production of new organic matter is an indirect consequence of the biological treatment process. Biotreatment is carried out in tanks or similar structures, where retention time, temperature, nutrient flow, and duration of contact with the bacteria are controlled (ANL 1998).

Biotreatment will be used at Aberdeen Proving Ground (APG) as a secondary treatment process (following hydrolysis) as part of a pilot test for treatment of the bulk HD that is stored at APG (PMCD 1998a, ANL 1998). Many studies have been conducted on the efficacy of biotreatment processes. In 1993, for example, NRC studied biotreatment in conjunction with the treatment of chemical agents and the treatment of products of chemical agent hydrolysis (NRC 1993).

1.4.2.5 Electrochemical Oxidation

Electrochemical oxidation is an electrochemical process that uses an electrical current to create a strong oxidizing environment. Theoretically, organic compounds contained in input streams are oxidized to CO_2, inorganic salts/acids, and water. The process can be considered a primary treatment process amenable to both agent and energetic streams in which no further treatment (e.g., to destroy Schedule 2 compounds) is needed. Metal parts and other solids, however, are not amenable to treatment using this technology.

The process proposed in the ACWA program employs SILVER II,™ an electrochemical oxidation process that uses silver nitrate ($AgNO_3$) and concentrated nitric acid (HNO_3). The process involves the use of an industrial electrochemical cell. The electrochemical cell contains platinized titanium electrodes and has one cell compartment consisting of an anode flanked by two cathodes (PMACWA 2001b). The cell compartments are separated by permeable membranes made of a perfluoro ion-exchange polymer. Organic feed is fed continuously into the anolyte cell that contains the $AgNO_3$ and HNO_3. When the current is turned on, SILVER II (Ag^{2+}) ions are created, and the oxidation reaction is initiated. Ag^{2+} is one of the strongest oxidizing agents (NRC 1999). The process relies on the oxidizing capabilities of the Ag^{2+} ions and operates at relatively low temperatures (194°F [90°C]) and near atmospheric pressure (NRC 1999). NRC (1999) discusses the process chemistry involved in the SILVER II process.

1.4.3 ENERGETICS TREATMENT TECHNOLOGIES

1.4.3.1 Baseline Incineration (Deactivation Furnace/Rotary Kiln Incinerator)

As with the chemical agents, baseline incineration of energetics from ACW was the technology used at JACADS and is the technology being used for TOCDF. In addition, incineration systems are being constructed at PBA, UMDA, and ANAD. The technology used at these locations for incineration of energetics is a deactivation furnace system (DFS). The DFS consists of a rotary kiln furnace and a heated discharge conveyor (HDC). The kiln is explosive-hardened and designed to safely destroy energetic compounds, including bursters, propellant, fuzes, and initiators. The HDC, modified as appropriate, is used in some of the proposed ACWA technology systems.

1.4.3.2 Hydrolysis

Hydrolysis is used to treat energetics as well as agents. While water or caustic (e.g., NaOH) can be used for the mustard agents, hydrolysis with NaOH is used for energetics. The process reaction is the same as that discussed for treatment of agent in Section 1.4.2.2. As with agent, hydrolysis is quite effective in breaking down the parent energetic compound; however, it does not necessarily reduce all hazards. Thus, a secondary treatment process will be used to destroy hydrolysis breakdown products. Caustic hydrolysis of energetic compounds is discussed extensively in NRC (1999).

1.4.3.3 Supercritical Water Oxidation

SCWO is a secondary treatment process used for energetics as well as agents. The process for energetic hydrolysates is chemically identical to that used for agent hydrolysates (see

Section 1.4.2.3). SCWO of energetic hydrolysates is applied as part of two of the candidate ACWA technology systems and as a secondary treatment process for both agent and energetic hydrolysates.

Either a solid-wall or TW-SCWO may be used for destroying residual organic compounds from energetics hydrolysis. The same basic unit and processes are employed as discussed in Section 1.4.2.3.

1.4.3.4 Biotreatment

Biotreatment is a secondary treatment process that can be used in conjunction with primary treatment for chemical agent and energetics. The process for energetic hydrolysates is identical to that used for agent hydrolysates (see Section 1.4.2.4). Many studies have been conducted on the efficacy of biotreatment processes. In 1993, for example, the U.S. Environmental Protection Agency (EPA) studied biotreatment in conjunction with treatment of energetics (EPA 1993).

1.4.3.5 Electrochemical Oxidation

The electrochemical oxidation process used for energetics is nearly identical to that applied for agents. Section 1.4.2.5 provides an overview of the technology as applied to agents. The process for energetics used in the ACWA demonstration test program differs from the process for agents in that it operates with a complete nitrous oxide (NO_X) reformer circuit. It also operates without a particulate removal and treatment system (PMACWA 2001b).

1.4.4 METAL PARTS TREATMENT TECHNOLOGIES

The two primary means of treating metal parts are thermal treatment and chemical treatment. Metal parts are thermally treated to remove residual agent and energetics in the baseline incinerator, MPF, and DFS. These technologies are used in combination with HDCs. They also are used, with modifications, as part of some ACWA treatment systems. Hydrolysis processes (a chemical process) are used as a primary treatment to destroy residual agents and energetics on munition components.

Surface washing is used to remove residual agent and energetics from hardware. The ATP uses high-pressure hot water to surface-decontaminate TCs to a 3X condition. Chemical reagents (e.g., supertropical bleach and high-test hypochlorite) are routinely used to decontaminate equipment in chemical demilitarization facilities.

With respect to treatment of metal parts to destroy chemical agent, the technology or combination of technologies that is used is designed to achieve a 5X condition, per U.S. Army requirements described in DA Pamphlet 385-61 (U.S. Army 1997). In so doing, the treated metal parts may be released from U.S. Army control for subsequent recycling.

The following subsections give details and descriptions of the treatment technologies for agent and energetics on metal parts.

1.4.4.1 Treatment of Metal Parts for Chemical Agent

1.4.4.1.1 Baseline Incineration (Stationary Bed Incinerator)

The baseline process for treating metal parts for chemical agent is thermal treatment to a 5X condition. Metals decontaminated to a 5X condition are generally not considered hazardous waste and may be recycled.

1.4.4.1.2 Projectile Rotary Hydrolyzer

A projectile rotary hydrolyzer (PRH) may be used to surface-wash metal parts resulting from the cryofracture process to destroy chemical agents (General Atomics 1999). Metal parts are first flushed by using high-pressure hot water. Then, hydrolysis with water at an elevated temperature (i.e., 212ºF [100ºC]) is used in the PRH to hydrolyze the residual agent that may be present on the metal parts. A screen is used to separate metal parts from the hydrolysate. The hydrolysate is collected in a tank and eventually transferred to the agent hydrolysis system, while the metal parts proceed to a HDC (described below).

1.4.4.1.3 Projectile Heated Discharge Conveyor

The HDC is one of a series of thermal treatment technologies that is used to treat metal parts (NRC 1999). The HDC is a baseline process. The baseline process can be modified, however, to increase residence time and operating temperatures, such that a 5X condition (i.e., greater than 1,000ºF [538ºC] for at least 15 minutes) is achieved (General Atomics 1999). In addition, the baseline HDC involves direct fire combustion, whereas the ACWA technology involves an electrically heated system.

1.4.4.1.4 Metal Parts Furnace

Metal, glass, and other solids from dunnage may be treated in an MPF. The ACWA MPF is similar to the baseline MPF except that it is smaller, it is induction-heated (not direct-fired combustion), and it has an inert nitrogen atmosphere. The ACWA MPF electric induction furnace can be used to treat metal parts contaminated with agent and energetics. Both types of furnaces are designed to treat solids to a 5X condition (i.e., greater than 1,000ºF [538ºC] for at least 15 minutes) (General Atomics 1999).

1.4.4.1.5 Metal Parts Treater

In the metal parts treater (MPT), metal parts contaminated with agent are treated to a 5X condition in an autoclave-type device with superheated steam (NRC 1999). Within the MPT, induction heating coils and superheated steam at a pressure less than ambient (negative pressure) are used to raise the temperature of projectiles to meet a 5X condition (i.e., greater than 1,000ºF [538°C] for at least 15 minutes) (Parsons/Allied Signal 1999). The metal parts are assembled in a basket and treated in a batch process. At the end of the process, steam is swept with air to a condenser. The steam is condensed in a condensate recovery system, water is reused, and gases are passed on to a reheater and a catalytic oxidation unit (see Section 1.4.6.3).

1.4.4.1.6 Continuous Steam Treater

The continuous steam treater (CST) is a smaller version of the baseline DFS; the rotary kiln is heated by electrical induction and uses steam to react/remove off-gas. The CST is used to treat certain munition metal parts, such as fuzes, nose closure plugs, projectile burster casings, and fuze booster cups. This unit is a modified version of the MPT (previously discussed) that can operate in a continuous mode rather than batch (Parsons/AlliedSignal 1999). Its purpose is both to treat small metal parts that may contain energetics and that may also be contaminated with agent. The fuzes ignite or explode, while the small metal parts are treated to a 5X condition (NRC 1999).

1.4.4.1.7 Gas-Phase Chemical Reduction

Gas-Phase Chemical Reduction (GPCR™) is a process for treating metal parts, dunnage, and gas streams that emanate from other parts of the destruction facility. GPCR is a thermal system (operated at temperatures above 1,560°F [850°C]) that uses hydrogen in a steam atmosphere to reduce organic compounds to methane (CH_4), CO_2, carbon monoxide (CO), and acid gases (NRC 1999). The system includes solids treatment in a thermal reduction batch processor (TRBP), which uses a flame-heated batch evaporator to volatilize organic materials to the main GPCR reactor. If recovered gas from the process meets certain criteria, the recovered gas may be used as auxiliary fuel for a steam boiler or industrial furnace.

1.4.4.2 Treatment of Metal Parts for Energetics

This section addresses those treatment technologies designed to treat metal parts that contain energetics.

1.4.4.2.1 Baseline Incineration (Deactivation Furnace System, Rotary Kiln Incinerator)

The baseline process for treating metal parts contaminated with energetics is incineration in the DFS. The same type of deactivation furnace used to treat agent (see Section 1.4.3.1) may be used.

1.4.4.2.2 Energetics Rotary Hydrolyzer

The energetics rotary hydrolyzer (ERH), similar to the design and operation of the PRH (see Section 1.4.4.1.2), is used to treat metal parts containing energetics. A NaOH decontamination fluid is used to hydrolyze the energetic compounds in a batch mode (General Atomics 1999). The wash operates at atmospheric pressure and approximately 194ºF (90ºC), which is above the melting point of the energetics (NRC 1999). The combination of rotary mixing and melting dissolves the energetics and cleans the metal surfaces. This process starts hydrolysis, which converts the solid explosives and other energetics into a hydrolysate that can then be further treated (see Section 1.4.3.2), if necessary (NRC 1999).

1.4.4.2.3 Hardware Heated Discharge Conveyor

The hardware HDC is a unit similar in design to the projectile unit discussed in Section 1.4.4.1.3. Separate conveyors may be used for the treated hardware (energetics) and the treated projectiles. Whereas this type of HDC is a baseline technology, the projectile conveyor used in ACWA systems can be a modified baseline technology.

1.4.4.2.4 Metal Parts Furnace

See Section 1.4.4.1.4. The MPF is a nonopen-flame, electric induction furnace (NRC 1999) used to treat agent and energetics. It is designed to treat solids to a 5X condition (i.e., greater than 1,000ºF [538ºC] for at least 15 minutes) (General Atomics 1999).

1.4.4.2.5 Metal Parts Treater

See Section 1.4.4.1.5. The same process and equipment used to treat agent-contaminated metal parts is used to treat metal parts contaminated with energetics.

1.4.4.2.6 Continuous Steam Treater

See Section 1.4.4.1.6. The same process and equipment used to treat agent-contaminated metal parts is used to treat metal parts contaminated with energetics.

1.4.4.2.7 Gas-Phase Chemical Reduction

The GPCR unit referred to in Section 1.4.4.1.7 may also be used to destroy residual energetics on metal parts. The same basic unit and processes are employed as discussed in Section 1.4.4.1.7.

1.4.5 DUNNAGE TREATMENT TECHNOLOGIES

Treatment technologies are designed to treat dunnage for chemical agent contamination. While the agent, which is liquid in nature, may leak and contaminate dunnage, energetics are solid in nature and will not typically escape the confines of the munition itself, even if agent does leak. Typically, dunnage will only become contaminated with agent if a leaker has contaminated the pallet or other packing materials. Dunnage may therefore first be evaluated to determine whether it is contaminated. If it is not contaminated, the dunnage could be disposed of as a nonhazardous waste without prior treatment. If it is contaminated, dunnage may be treated using the same basic technologies as those used for metal parts. All dunnage may be considered contaminated and subject to treatment.

Dunnage may be prepared for treatment using shredders, hammer mills, micronizers, macerators, and pulpers, as appropriate (see Section 1.4.1.5). The baseline process for treating dunnage is incineration in a dunnage incinerator, a roller hearth incinerator. The same basic technologies used to treat agent-contaminated metal parts can be applied to treat dunnage. These include caustic hydrolysis, thermal treatment, GPCR, and steam treatment as primary treatment technologies, and SCWO and biotreatment as secondary treatment technologies.

The GPCR unit referred to in Section 1.4.4.1.7 is also used to destroy residual agent and energetics on dunnage. The TRBP unit, in particular, not only volatilizes organic materials from these solids but is capable of vaporizing organic matrices such as cellulose and plastics. The same basic unit and processes are employed as discussed in Section 1.4.4.1.7.

1.4.6 EFFLUENT MANAGEMENT AND POLLUTION CONTROL TECHNOLOGIES

A number of different technologies are used to treat the various liquid, solid, and gaseous streams produced by the various technologies previously discussed. Many of the technologies simply process the stream(s) produced by a previous technology and further treat it. For example, liquid hydrolysates (both agent and energetic) may be further treated using chemical (e.g., solid wall-SCWO or TW-SCWO) or biological treatment. Effluents from these technologies are then further treated by using various other technologies, which are ultimately designed to produce process waste streams that can be reused within the facility (e.g., process water), that can be recycled (e.g., 5X metals), or that are amenable to disposal as hazardous or nonhazardous solid wastes.[19] Gaseous waste streams are also produced, and these are treated with a number of technologies prior to being released to the atmosphere.

The following subsections discuss effluent management and pollution control technologies as applied to waste streams. The ACWA technology systems were developed to permit wastes that leave the facility to be held and tested prior to release (PMACWA 1999a,b).

1.4.6.1 Liquid Waste Streams

While liquid waste streams are produced by the various baseline and ACWA technologies, these waste streams are processed or treated so that they can be reused in the chemical demilitarization facility (e.g., process water); residues are evaporated or solidified to eliminate the presence of free liquids. With minor exceptions, no liquid waste streams (other than domestic sewage) are intended to leave the actual facility.

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[19] Waste containing free liquids is prohibited from land disposal by the Hazardous and Solid Waste Amendments of 1984.

1.4.6.2 Solid Waste Streams

All solid waste streams produced by the various ACWA technology systems are held and tested prior to release. The primary solid waste streams produced are identified in the subsections below.

1.4.6.2.1 Recycling

As previously indicated, liquid waste streams (e.g., recovery of condensate from steam treatment) are reused within the facility. Materials that have been treated to a 5X condition, and especially 5X metals, may be recycled. Grit from fluid-abrasive cutting operations may also be reused in the operation.

Used process equipment that meets a 5X condition and that is not otherwise defined as hazardous waste under federal or state law may be reused or recycled, as appropriate. The Rock Island Arsenal (Rock Island, Illinois) operates a smelter that is permitted to accept metals for recycling from demilitarization operations (CBDCOM 1997).

1.4.6.2.2 Hazardous Waste Landfill[20]

Baseline incineration and similar thermal treatment processes produce a number of solid wastes, such as ash, slag, and carbon-based residues, that may be disposed of in a permitted hazardous waste landfill.

Following completion of certain processes (e.g., SCWO or TW-SCWO), resulting liquid streams are dried in a brine reduction area (BRA). Resulting solids are dried salts that contain traces of organic materials and potentially heavy metals. These salts are intended for disposal in a permitted hazardous waste landfill.

Biotreatment results in a biosludge. The biosludge is produced using standard wastewater treatment equipment (e.g., flocculation, clarification, solidification). The biosludge would be disposed of in a permitted hazardous waste landfill.

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[20] If a waste stream is deemed hazardous under federal or state law, generators may choose to demonstrate that the waste is nonhazardous (referred to as an exclusion; see Title 40, Part 260.22, of the *Code of Federal Regulations* [40 CFR 260.22]). If the demonstration is successful, the waste is "delisted" and may be disposed of as a nonhazardous solid waste.

Fluid-abrasive cutting operations result in a grit material (e.g., garnet) that would be disposed of in a permitted hazardous waste landfill. The grit could also be reused in the fluid-abrasive cutting process.

High-efficiency particulate air (HEPA) filters are designed to remove particulate matter from the air stream, while carbon filters are designed to absorb any chemical agent and/or other organic compounds that escape into the gaseous phase. Each type of filter can be used in these treatment processes. Such filters, which could contain small amounts of chemical agent, could potentially be treated on-site (e.g., SCWO processes, thermal treatment), or could be disposed of as hazardous waste in a permitted hazardous waste landfill.

The baseline incineration and ACWA systems include scrubbers as part of the basic pollution abatement system (PAS). The caustic solution, called scrubber brine, is then dried within the BRA and disposed of as a solid waste. Drum dryers and other evaporative devices may be used for this purpose. Because the dried brine salts may contain heavy metals, brine salts are often disposed of in a permitted hazardous waste landfill.

Used process equipment that either does not meet a 5X condition or that is otherwise defined as hazardous waste under federal or state law may be disposed of in a permitted hazardous waste landfill.

1.4.6.2.3 Nonhazardous Waste Landfill

Noncontaminated dunnage may be disposed of as nonhazardous waste, as long as it is not otherwise defined as hazardous waste under federal or state law.

Furthermore, any material that has received treatment to a 5X condition and that is not otherwise defined as hazardous waste under federal or state law may be reused or recycled or disposed of as nonhazardous waste. Used process equipment that meets a 5X condition and that is otherwise not defined as hazardous waste under federal or state law may be disposed of as nonhazardous waste.

1.4.6.3 Gaseous Waste Streams

The operation of treatment facilities is likely to result in the generation of certain gaseous, liquid, or solid waste streams. The following sections describe specific environmental technologies commonly used to treat potential contaminants within these waste streams.

Monitoring of emissions is part of any environmental waste management scenario. Monitoring of ACW treatment processes will be prescribed in environmental permits issued under RCRA. Monitoring technologies are not specifically addressed in this TRD.

1.4.6.3.1 Condenser/Scrubber

Scrubbers are commonly used pollution control devices designed to promote the contact of the gaseous waste stream and the pollutants contained therein with a liquid solution. The liquid solution is selected for its ability to collect or neutralize the pollutants of concern from the gas stream. An aqueous solution of NaOH is commonly used for acid gases, such as those from the treatment of chemical agents. The caustic solution, called scrubber brine, is then dried and disposed of as a solid. As previously indicated, because the dried brine salts may contain heavy metals, brine salts are often disposed of as hazardous waste. Condensers and scrubbers are part of the PAS used in the baseline process.

1.4.6.3.2 Filtration/Carbon Absorption

Gases from process vents, from various building areas (e.g., heating, ventilation, air-conditioning) or treatment technologies are often passed through HEPA filters and a series of activated carbon filters prior to release to the atmosphere. The HEPA filters are designed to remove particulate matter from the air stream, while the carbon filters are designed to absorb any chemical agent/other organic compounds that escape into the gaseous phase. Used filters could potentially be treated on-site (e.g., SCWO processes, thermal treatment) or disposed of in a hazardous waste landfill. Filtration/carbon absorption processes are part of the PAS used in the baseline process.

1.4.6.3.3 Catalytic Oxidation

Catalytic oxidation covers a broad range of technologies in common use throughout industry to reduce contaminants from gaseous streams to less hazardous compounds. Most cars, for example, have catalytic converters that reduce organic products of incomplete combustion from engine exhaust. Catalytic oxidation is appropriate for dilute concentrations of organic contaminants in a gaseous stream. A catalyst is used to speed the rate of chemical oxidation while not interfering with the reaction itself. The catalyst combines with one of the reactive compounds to form an intermediate substance that then reacts more readily with the other reacting compounds. With respect to the ACWA program, catalytic oxidation can be used to facilitate the oxidation of chemical agents and degradation products. The resulting products consist primarily of CO_2, water vapor, and inorganic compounds.

1.4.6.3.4 Peroxide/Ultraviolet Treatment/Oxidation

Peroxide/ultraviolet (UV) treatment of liquids from sludge clarification/ flocculation may be used to oxidize any remaining organic material in the water stream prior to its reuse within the system.

1.4.6.3.5 Drum Dryers

Steam from drum dryers used to dry salts, biomass (from biotreatment), and similar wastes are released to the atmosphere. Steam may be passed through HEPA and carbon filters prior to release.

1.4.6.3.6 Gas-Phase Chemical Reduction

GPCR is a thermal system (operated at temperatures above 1,560°F [850°C]) that uses hydrogen in a steam atmosphere to reduce organic compounds to CH_4, CO_2, CO, and acid gases. The system includes solids treatment in a TRBP, which uses a flame-heated batch evaporator to volatilize organic materials to the main GPCR reactor (NRC 1999).

1.4.7 TREATMENT OF LEAKING MUNITIONS AND LEAKERS

Following initial handling of leaking munitions[21] or overpacked leakers, the remaining treatment process for components of the ACW is identical to that for initially intact munitions. The primary difference is in the unpack and munitions access processes, which, in general, will not differ as a function of the general destruction technology employed (e.g., incineration versus hydrolysis). The process is slightly different for leaking munitions as compared to leakers. In general, the munition item(s) are manually unpacked by personnel in protective suits in a containment room designed to contain agent vapors. The munition is then dismantled in a manner identical to the process used for intact items.

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[21] Leaking munitions are munitions that are determined to have leaked during the process of transporting them from storage to the destruction facility.

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1.5 REFERENCES

ANL: See Argonne National Laboratory.

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APPENDIX A:

CHEMICAL MUNITIONS SPECIFIC INFORMATION

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FOREWORD

This document provides general background information on the assembled chemical weapons maintained in the unitary chemical stockpile. For each munition type, agent, energetic, and other components are reviewed. The following types of assembled chemical weapons are included in this document:

155-mm projectiles
4.2-in. mortar cartridges
105-mm projectiles
8-in. projectiles
M55 rockets
M23 land mines

The information contained in this appendix is excerpted from Appendix J3 of the following reference:

U.S. Army, 1997, *Assessment of Technologies for Assembled Chemical Weapon Demilitarization*, Solicitation Number DAAM01-97-R-0031, U.S. Army Chemical and Biological Defense Command, Aberdeen Proving Ground, Md., July 28.

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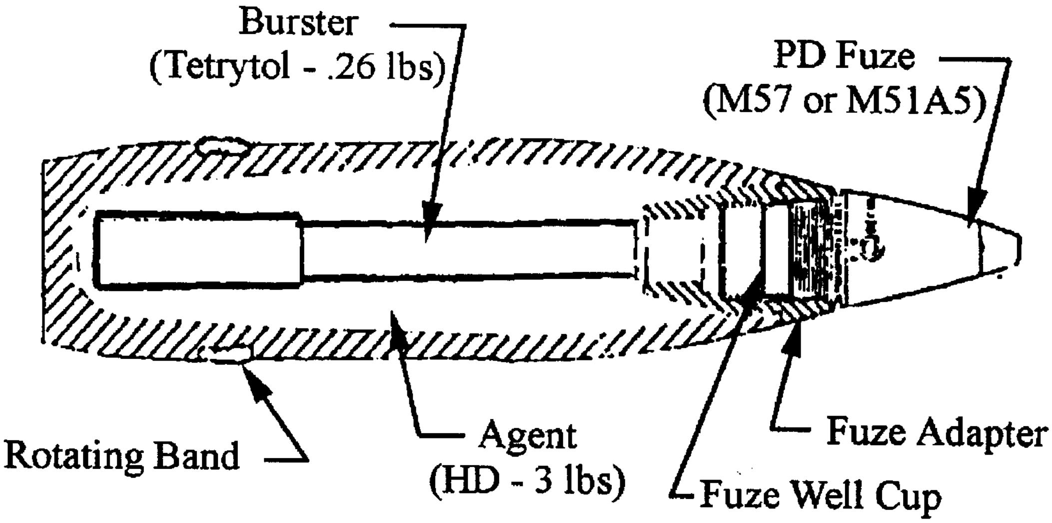
J.3

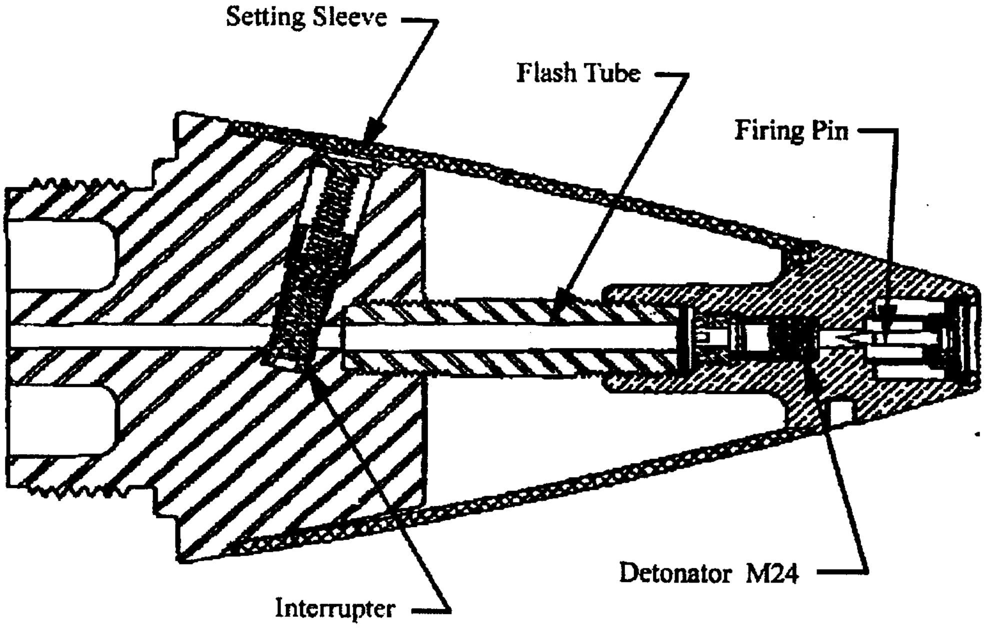
CHEMICAL MUNITION SPECIFIC INFORMATION FOR THE ASSEMBLED CHEMICAL WEAPON ASSESSMENT PROGRAM

1315-C442 CARTRIDGE 105mm M60 HD

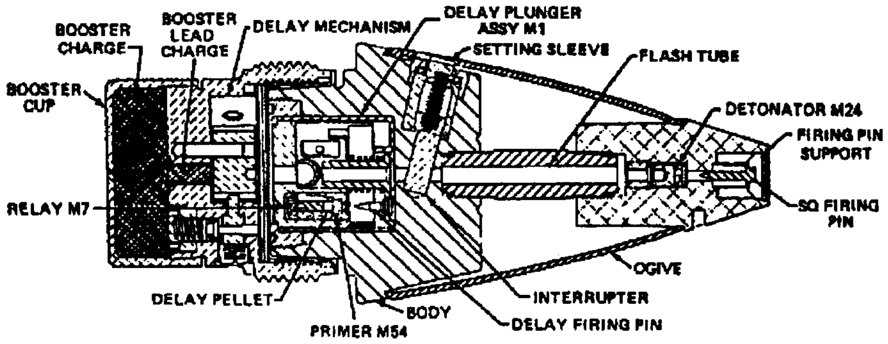


1315-00-028-4829 w/PD FZ M57
1315-00-322-6365 w/PD FZ M51A5

M60 - The body of this 105mm projectile consists of a hollow one-piece steel forging. A fuze adapter is screwed into the body and brazed in place. The agent is added and the burster well is then press-fit into the fuze adapter followed by the M5 tetrytol burster being installed into the burster well. A fuze well cup, made of either aluminum or Bakelite™, is installed by first coating the lower interior threads of the fuze adapter with sealing compound or cement and then screwing the cup down into the fuze adapter. The M60 is then closed by screwing on an M57 or M51A5 point detonating fuze and staking it in place. Staking is an operation in which a punch is used to deform the metal of the fuze so that the metal is pushed into a notch in the projectile body, thereby locking the threaded joint. The projectiles are stored 24 per wooden pallet with 2 pallets butted together and secured with steel banding.



Point Detonating Fuze M57



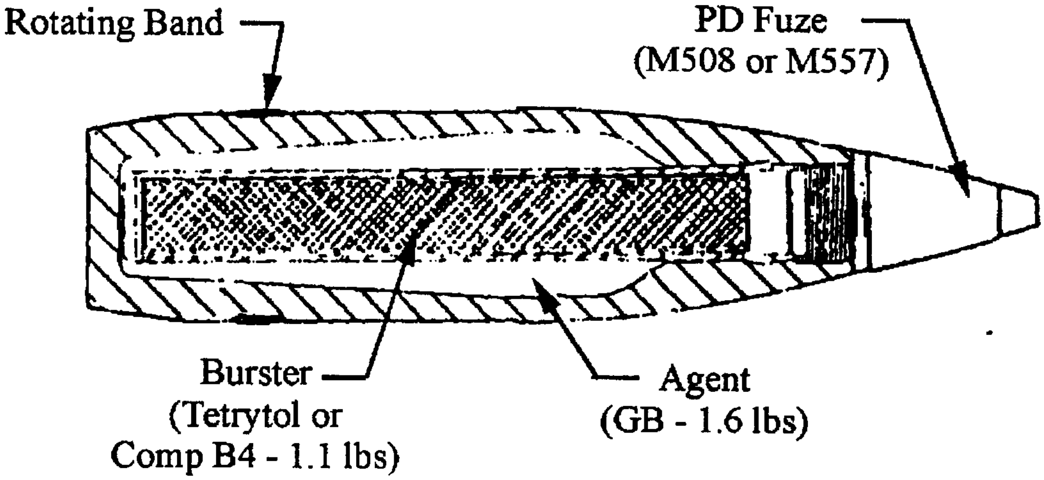
Point Detonating Fuze M51A5

M51A5 - The M51A5 fuze consists of Fuze M48A3 assembled with the M21A4 booster. The fuze PD head assembly contains a firing pin held in position by a firing pin support which prevents initiation of Detonator M24 until impact. The fuze body contains an M1 delay plunger assembly and an interrupter assembly with a setting sleeve, which provides a means of setting or selecting fuze PD (Super Quick Action) or delay functioning. The delay plunger assembly includes a firing pin and Delay Element M2. The delay element includes Primer M54, a black powder delay charge and Relay M7. The head assembly is attached to the body by means of the flash tube, which also positions the fuze windshield or ogive. The ogive is a thin-walled steel stamping utilized to provide an aerodynamic shape to the fuze. The M21A4 booster consists of a brass booster body having external (male) threads to fit projectiles having 2 inch diameter; 12 threads per inch and internal (female) threads to receive fuzes having 1.7 inch diameter; 14 threads per inch. An aluminum booster cup containing a 340-grain tetryl booster pellet is threaded to the booster body. The M21A4 booster internal configuration is that of an eccentric rotor containing an M17 detonator held in an unarmed (out of line) position by centrifugal and setback lock pins.

The energetic components of the M51A5 fuze consist of the following:

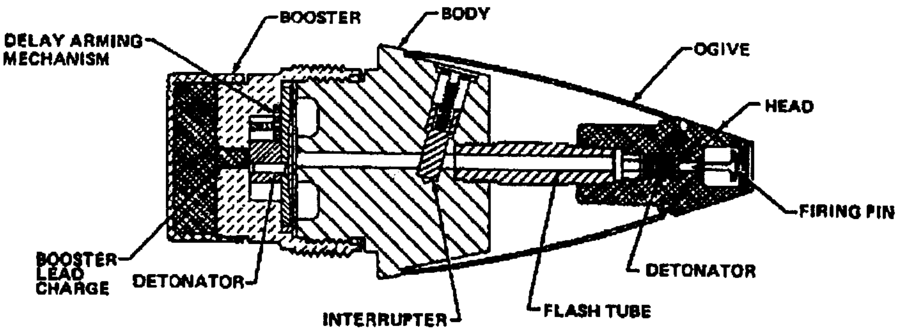
- M24 Detonator
  - 68 mg AN #6 Priming Mix
    - 33.4% $KClO_3$
    - 33.3% Sb_2S_3
    - 28.3% lead azide
    - 5.0% carborundum
  - 185 mg lead azide
- Black powder delay - variable
- M7 Relay - 100 mg lead azide
- Booster
  - M17 detonator
    - 280 mg lead azide
    - 80 mg tetryl
  - booster lead charge - tetryl
  - booster pellet - 340 grains tetryl

1315-C441 CARTRIDGE 105mm M360 GB



1315-00-203-8985 w/PD FZ M508
1315-01-082-1234 w/PD FZ M557

M360 - The body of the projectile is cast and finished from low-carbon steel. GB agent is added to the interior of the body and sealed inside by press-fitting a steel burster well into the body. The M16 burster casing, containing an M40 tetrytol charge or an M40A1 composition B4 charge, is installed in the burster well. The assembly is completed by screwing an M508 or M557 point detonating fuze onto the nose of the projectile and staking it in one or more locations. The projectiles are stored 24 per wooden pallet with 2 pallets butted together and secured with steel banding.

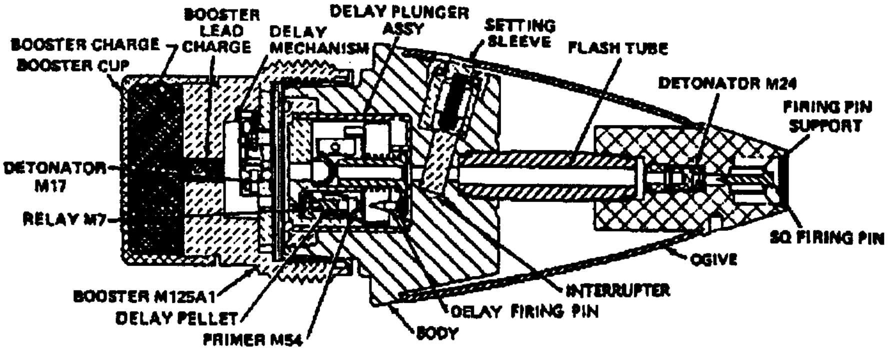


Point Detonating Fuze M508

M508 - The M508 fuze consist of a PD head assembly containing a firing pin held in position by a firing pin support which prevents initiation of Detonator M18 until impact; a stamped steel ogive to provide an aerodynamic shape to the fuze; a fuze body containing an interrupter assembly to provide bore safe firing; and an M125A1 or M125 booster assembly. The boosters are physically similar. The threaded brass body of the booster contains a delayed arming mechanism, Detonator M17, and a tetryl lead charge. The delayed arming mechanism is operated by centrifugal force acting through a gear train to turn a rotor carrying Detonator M17. In the unarmed position, the detonator is held out of line with the flash hole in the booster cover by rotor detents. An aluminum cup containing a 340-grain tetryl charge is threaded onto the base of the booster.

The energetic components of the M508 fuze consist of the following:

- M18 Detonator - 65 mg AN #6 Priming Mix
    - 33.4% $KClO_3$
    - 33.3% Sb_2S_3
    - 28.3% lead azide
    - 5.0% carborundum
  - 190 mg lead azide
  - 82 mg tetryl
- Booster - M17 detonator - 280 mg lead azide
    - 80 mg tetryl
  - booster lead charge - tetryl
  - booster pellet - 340 grains tetryl



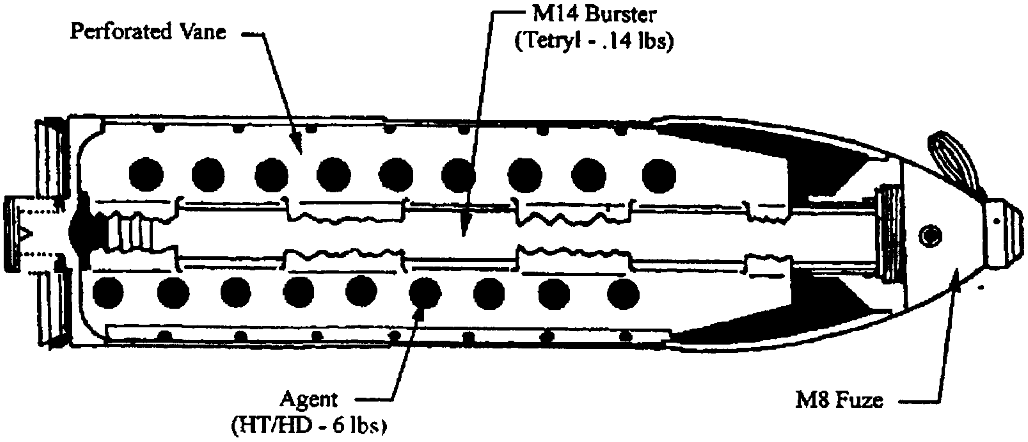
Point Detonating Fuze M557

M557 - The M557 fuze consists of Fuze M48A3 assembled with the M125A1 booster. The fuze PD head assembly contains a firing pin held in position by a firing pin support which prevents initiation of Detonator M24 until impact. The fuze body contains an Ml delay plunger assembly and an interrupter assembly with a setting sleeve which provides a means of setting or selecting fuze PD (Super Quick Action) or delay functioning. The plunger assembly includes a firing pin and Delay Element M2. The delay element includes Primer M54, a black powder delay charge and Relay M7. The head assembly is attached to the body by means of the flash tube which also positions the fuze ogive. The ogive is a thin-walled steel stamping utilized to provide an aerodynamic shape to the fuze. The M125A1 booster consists of a brass booster body having external (male) threads to fit projectiles having 2-inch diameter, 12 threads per inch and internal (female) threads to receive fuzes having 1.7 inch diameter, 14 threads per inch. An aluminum booster cup containing a 340 grains tetryl booster pellet is threaded to the booster body. The M125A1 booster internal configuration is that of an eccentric rotor containing an M17 detonator held in an unarmed (out of line) position by centrifugal detents and a gear train mechanism which provides for delayed arming of the booster assembly.

The energetic components of the M557 fuze consist of the following:

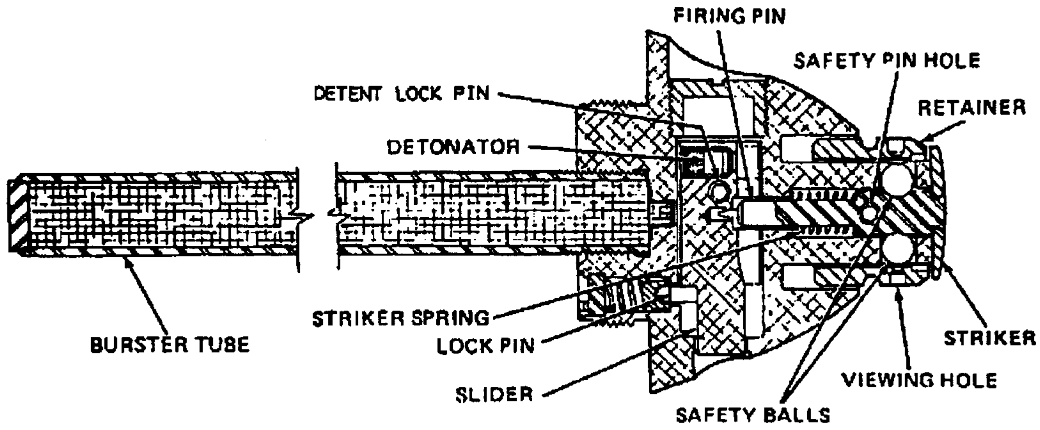
M24 Detonator - 68 mg AN #6 Priming Mix
33.4% $KClO_3$
33.3% Sb_2S_3
28.3% lead azide
5.0% carborundum
- 185 mg lead azide
Black powder delay - variable
M7 Relay - 100 mg lead azide
Booster - M17 detonator - 280 mg lead azide
- 80 mg tetryl
- booster lead charge - tetryl
- booster pellet - 340 grains tetryl

1315-C698 Cartridge 4.2 Inch M2 HT
1315-C703 Cartridge 4.2 Inch M2 HD



1315-00-028-5024 M2 HT w/PD FZ M8
1315-00-028-5018 M2 HD
1315-00-028-5027 M2A1 HD

M2 / M2A1 - This 4.2 inch projectile contains either HD or HT and has a perforated vane assembly welded to the inside of the body which is designed to accommodate the burster tube that extends from the fuze. The M2A1 has an aluminum pressure plate, the M2 has a steel plate. The M8 integral fuze includes the 14.062 inch M14 burster.

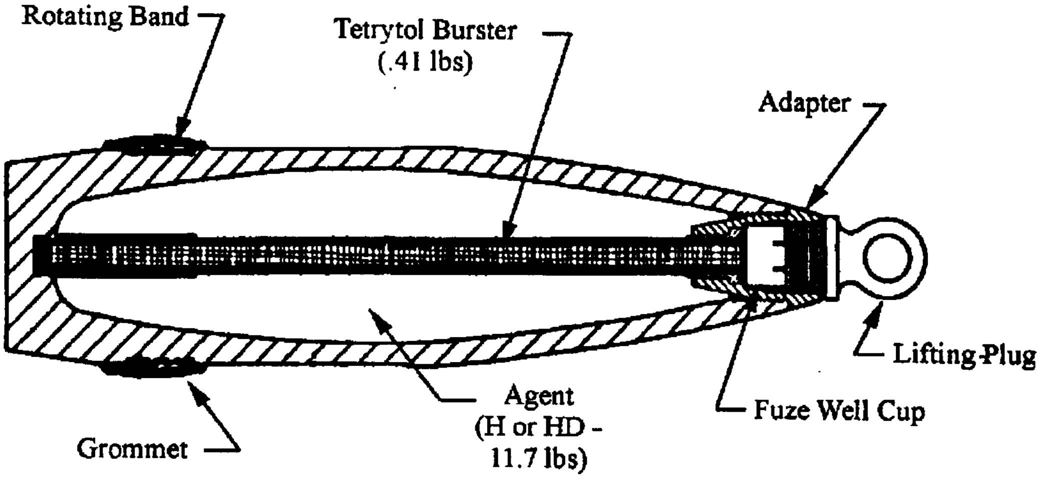


Point Detonating Fuze M8

M8 - The aluminum body of the fuze contains a spring-loaded striker at the nose mounted within a movable circular retainer. The striker and integral firing pin are retained in the unarmed position by a shear wire (not shown in illustration) and a removable safety pin.

Two safety balls are positioned by detents between the striker and the retainer. A slider, containing the detonator and designed to position the detonator in line with the firing pin, is mounted transversely in the fuze body and is secured by a setback pin. A hole or slot is present in the retainer of some fuzes for viewing the position of the safety balls. A 14-inch long burster tube is threaded into the base of the fuze.

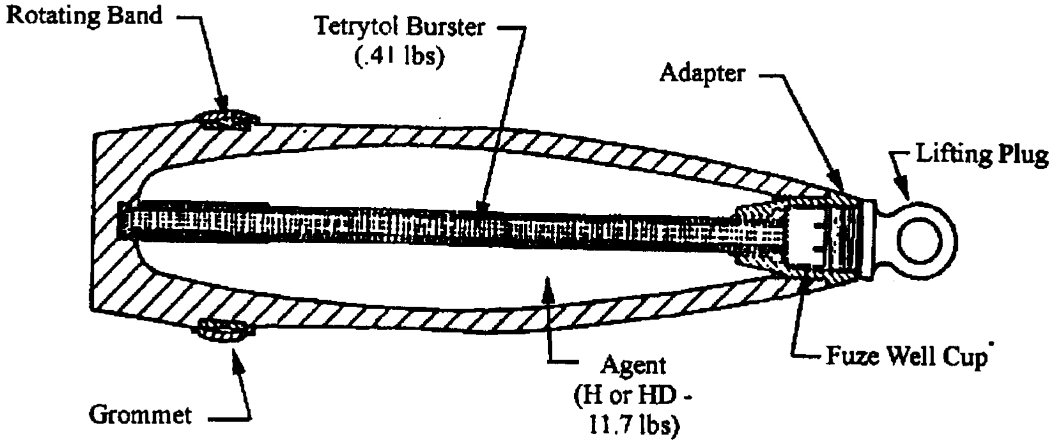
1320-D484 PROJECTILE 155mm M104 H, HD



1320-00-028-4348 HD Uncrated
1320-00-529-7350 HD 8/Pallet
1320-00-965-0704 H 8/Pallet

M104 - The body of this 155mm projectile consists of a hollow steel shell containing H or HD. A fuze adapter is screwed into the body and brazed in place. The agent is added and the burster well is then press-fit into the fuze adapter followed by the M6 Tetrytol burster being installed into the burster well. A fuze well cup made of either aluminum or Bakelite™ is installed by first coating the lower interior threads of the fuze adapter with sealing compound or cement and then screwing the cup down into the fuze adapter. The M104 is then closed by screwing on a lifting plug. The projectiles are stored unfuzed with 8 rounds per wooden pallet.

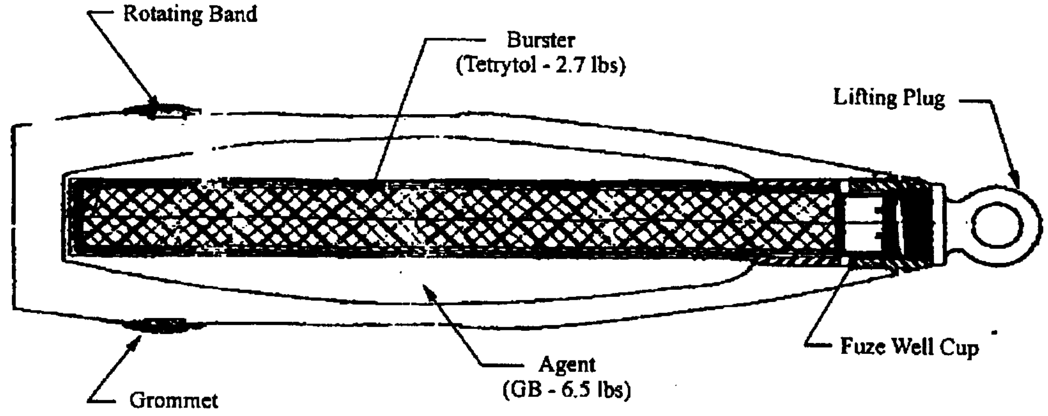
1320-D543 PROJECTILE 155mm M110 H, HD



1320-00-096-3067 HD Uncrated
1320-00-301-1824 H Uncrated
1320-00-529-7352 HD 8/Pallet
1320-00-529-7353 H 8/Pallet

M110 - The body of this 155mm projectile consists of a hollow steel shell containing H or HD. A fuze adapter is screwed into the body and brazed in place. The agent is added and the burster well is then press-fit into the fuze adapter followed by the M6 Tetrytol burster being installed into the burster well. A fuze well cup made of either aluminum or Bakelite™ is installed by first coating the lower interior threads of the fuze adapter with sealing compound or cement and then screwing the cup down into the fuze adapter. The M110 is then closed by screwing on a lifting plug. The projectiles are stored unfuzed with 8 rounds per wooden pallet.

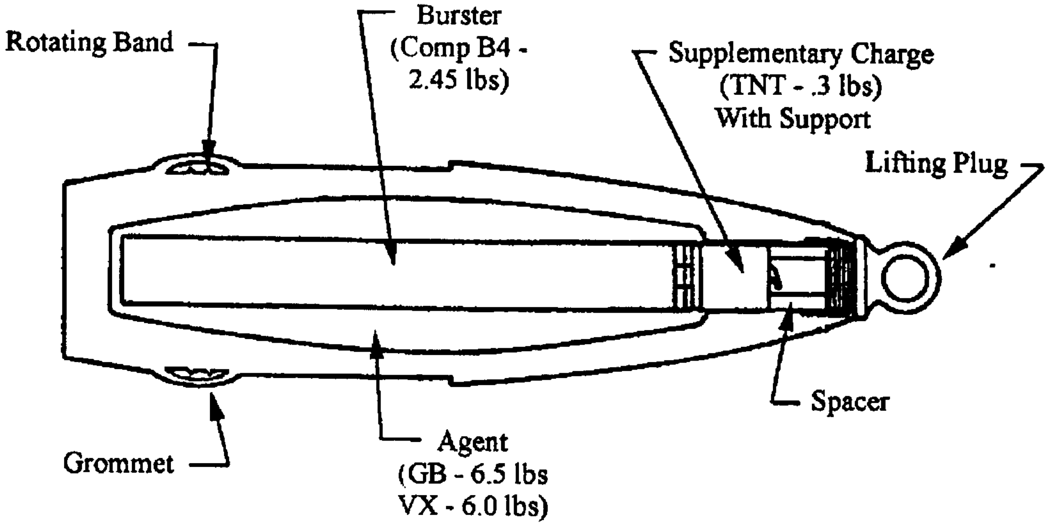
1320-D542 PROJECTILE 155mm M121 GB



1320-00-529-7346 M121 8/Pallet
1320-00-567-7909 M121 8/Wd box

M121 - This 155mm projectile starts as a hollow steel shell. GB agent is added and sealed inside by pressing the burster well into the body. The M37 tetrytol burster is then installed into the burster well. The fuze adapter is screwed in and staked to the body. Next, the lower interior threads of the fuze adapter are coated with sealing compound or cement. and the fuze well cup is screwed down into the fuze adapter. The lifting plug is then screwed into the fuze adapter. The projectiles are stored unfuzed with 8 rounds per wooden pallet.

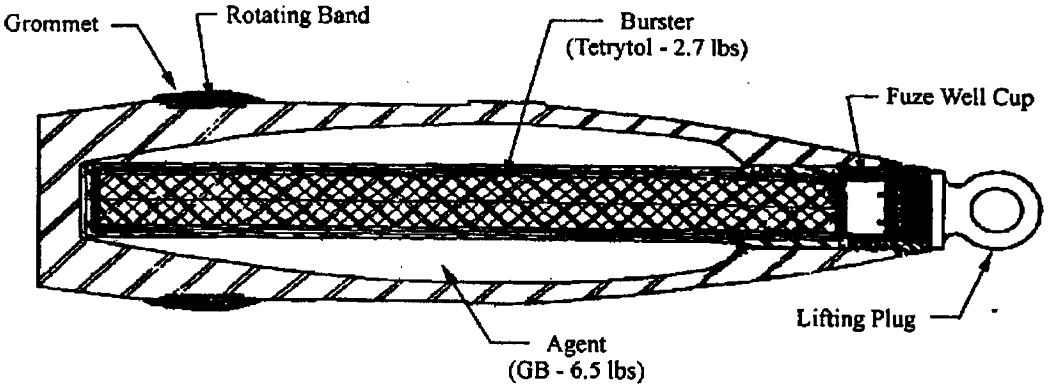
1320-D542 PROJECTILE 155mm M121A1 GB
1320-D568 PROJECTILE 155mm M121A1 VX



1320-00-143-7009 M121A1 8/Pallet
1320-00-756-2888 M121A1 8/Pallet

M121A1 - This 155mm projectile starts as a hollow steel shell. GB or VX agent is added and sealed inside by pressing the burster well into the body. The M71 composition B4 burster is then installed into the burster well. The charge support, the TNT supplementary charge, and the spacer are installed and the fuze adapter/lifting plug assembly is screwed into the body. The adapter is then staked in one or more places. The projectiles are stored unfuzed with 8 rounds per wooden pallet.

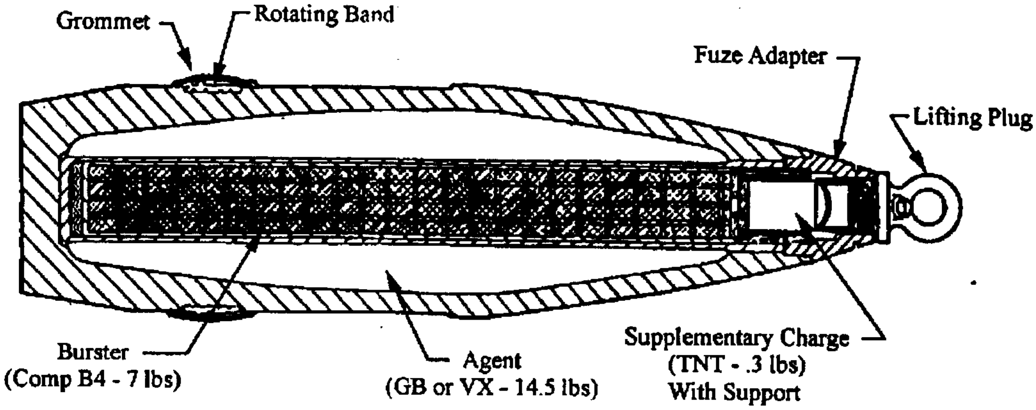
1320-D483 PROJECTILE 155mm M122 GB



1320-00-529-9033 M122

M122 - This 155mm projectile starts as a hollow steel shell. GB agent is added and sealed inside by pressing the burster well into the body. The M37 Tetrytol burster is then installed into the burster well. The fuze adapter is screwed in and staked to the body. Next, the lower interior threads of the fuze adapter are coated with sealing compound or cement, and the fuze well cup is screwed down into the fuze adapter. The lifting plug is then screwed into the fuze adapter. The projectiles are stored unfuzed with 8 rounds per pallet.

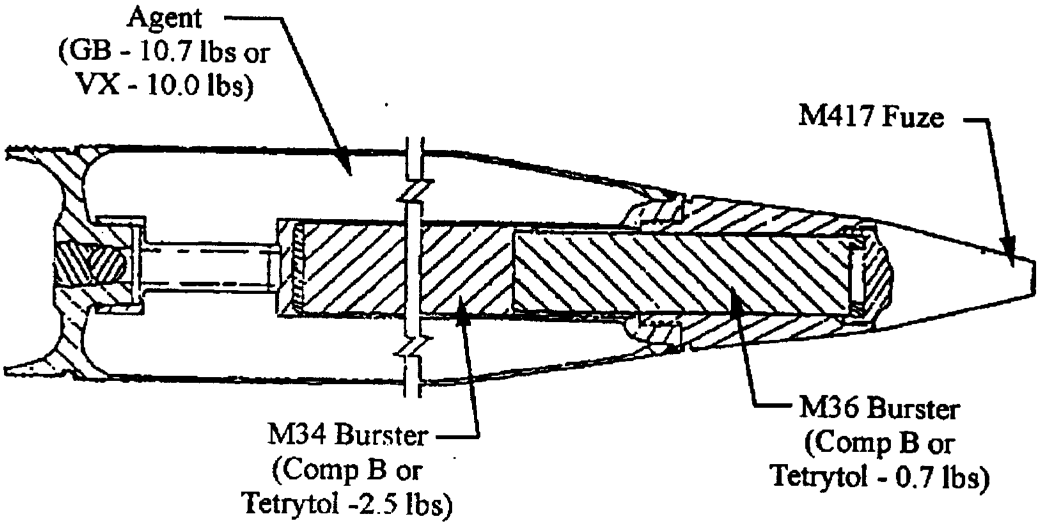
1320-D695 PROJECTILE 8 INCH M426 VX
1320-D696 PROJECTILE 8 INCH M426 GB



1320-00-763-6878 VX w/Burster M83
1320-00-763-6879 GB w/Burster M83

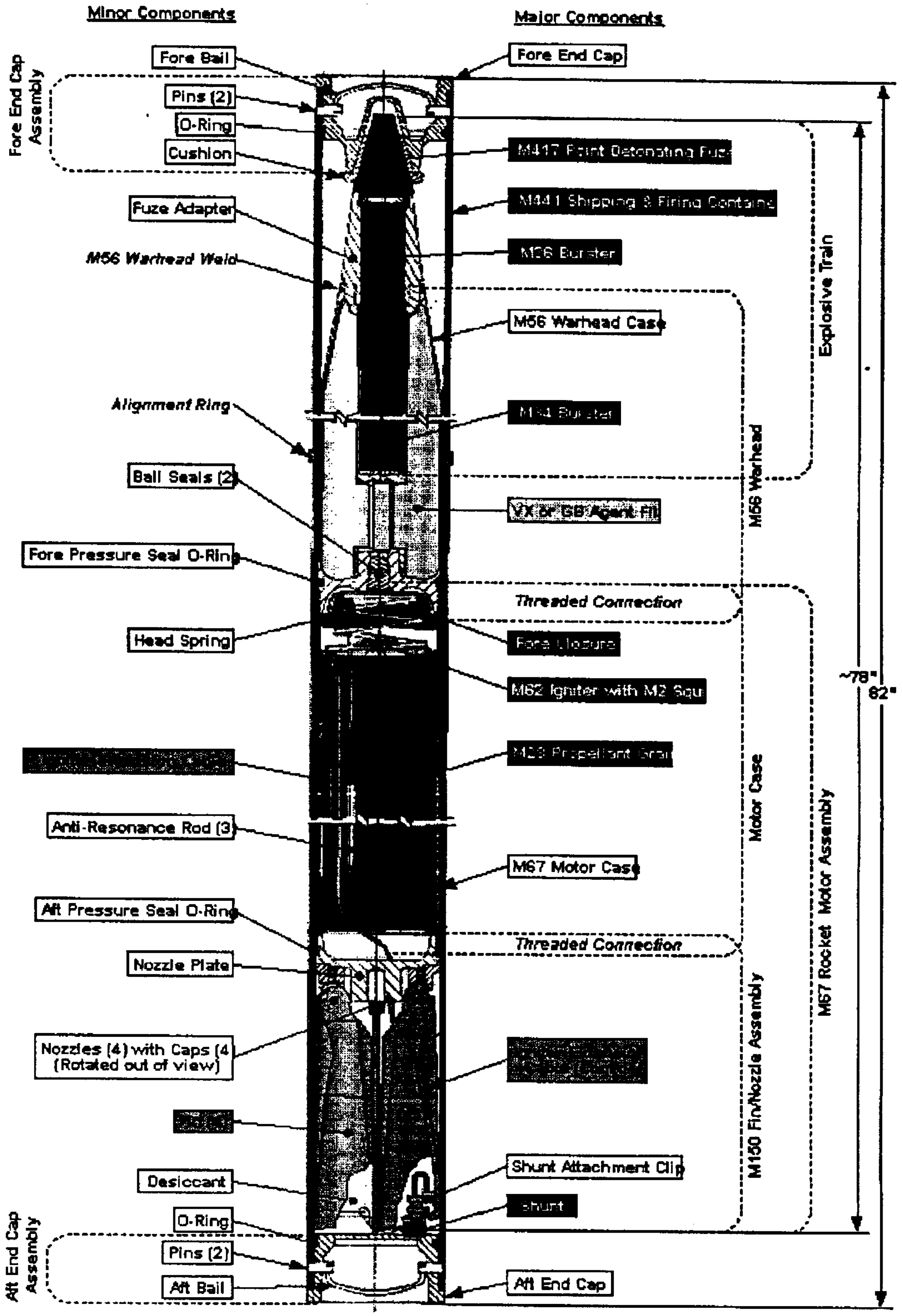
M426 - This 8 inch projectile starts as a hollow steel shell. GB or VX agent is added and sealed inside by pressing the burster well into the body. The M83 composition B4 burster is then installed into the burster well. The charge support, the TNT supplementary charge, and the spacer are installed and the fuze adapter/lifting plug assembly is screwed into the body. The adapter is then staked in one or more places. The projectiles are stored unfuzed with 6 rounds per pallet and secured with metal banding.

1340-H520 ROCKET 115mm M55 GB
1340-H521 ROCKET 115mm M55 VX



M56 Warhead Assembly

1340-00-716-1450 GB Rocket
1340-00-724-3567 VX Rocket


Minor Components
Major Components
Fore End Cap Assembly
Fore Bail
Pins (2)
O-Ring
Cushion
Fuze Adapter
M56 Warhead Weld
Alignment Ring
Ball Seals (2
Fore Pressure Seal O-Rin
Head Spring
[redacted]
Anti-Resonance Rod (3
Aft Pressure Seal O-Rin
Nozzle Plate
Nozzles (4) with Caps (4 (Rotated out of view)
[redacted]
Desiccant
O-Ring
Aft End Cap Assembly
Pins (2)
Aft Bail
Fore End Cap
M417 Point Detonating Fuz
M441 Shipping & Firing Containe
M36 Burster
M56 Warhead Case
M34 Burster
VX or GB Agent Fil
Threaded Connection
Fore Closure
M62 Igniter with M2 Squ
M28 Propellant Grai
M67 Motor Case
Threaded Connection
[redacted]
Shunt Attachment Clip
Shunt
Aft End Cap
Explosive Train
M56 Warhead
Motor Case
M150 Fin/Nozzle Assembly
M67 Rocket Motor Assembly
~78"
82"

M55 - The M55 rocket consists of a chemical agent filled warhead attached to a rocket motor. It has a diameter of 115 millimeters (4.44 inches). is 78 Inches long and weighs 57 pounds. The warhead is filled with either 10.7 pounds of GB or 10.0 pounds of VX.

The rocket is stored in a shipping and firing tube. The tube is made of fiberglass-reinforced resin, either epoxy or polyester, and in some cases contains PCBs. There is an indexing ring on the outside of the tube that is closer to the front or fuze end of the rocket. There are end caps on each end made of aluminum and secured to the tube by pins. Each end cap has a sampling port. When the rocket is placed in the tube, the igniter wire is plugged into a receptacle on the rear end cap.

The warhead consists of a body, a burster well containing two bursters in series, a fuze adapter, and a point detonating fuze. The body is a hollow thin-walled structure made of 6061 T6 alloy aluminum with a wall thickness of 0.058 plus 0.012 inch. The burster well is also made from 6061 T6 alloy aluminum and is welded to the body at the nose end. Inside the rocket body, the burster well terminates in an aluminum rod. The rod has a cup shaped fitting on the end, which fits over the fill port in the base of the warhead. The rear burster consists of a low carbon steel tube, with painted exterior and filled with Composition B or Tetrytol explosive. The forward burster consists of a plastic tube filled with Composition B or Tetrytol. The fuze contains a booster made from RDX explosive. Assembly of the fuze adapter to the warhead is made by coating the threads with either Pettman cement or sealing compound and then screwing it into the burster well. The fuze threads are also coated with either Pettman cement or sealing compound before the fuze is screwed into the fuse adapter. Agent is added to the warhead through a fill port in the base and then sealed inside by pressing two aluminum balls into the fill port.

The rocket motor consists of a body, nozzle-fin assembly, propellant, igniter assembly, and end cap. The body is a steel tube with a wall thickness of 0.096 - 0.008 inch, which is threaded on the interior of both ends. The nozzle-fin assembly is attached to the motor body by coating the threads with either Pettman cement or sealing compound and then screwing the assembly into the body. The propellant is an M28 double base (nitroglycerin and nitrocellulose) cast grain per MIL-P-60071 specification and weighs 19.3 pounds. It is installed by first bonding a spacer to one end, adding the igniter assembly, and then sliding the grain assembly into the tube until the spacer rests on the nozzle-fin assembly. Assembly of the rocket motor is completed by coating the threads of the end cap with either Pettman cement or sealing compound and then threading it into the body. When the end cap is installed, it compresses a spring on the igniter assembly to hold the propellant grain in place against the nozzle plate of the nozzle-fin assembly. The warhead is assembled to the rocket motor by coating the threads with either Pettman cement or a sealing compound and then screwing the two components together. The fins are normally in the retracted position. The rocket assembly is inserted into the shipping and firing container, the igniter wire is attached to the aft end cap, and the fore end cap is installed. The rockets are stored with 15 rounds per pallet assembly secured with metal banding.

The energetic components of the M417 fuze and M28 propellant are as follows:

Fuze

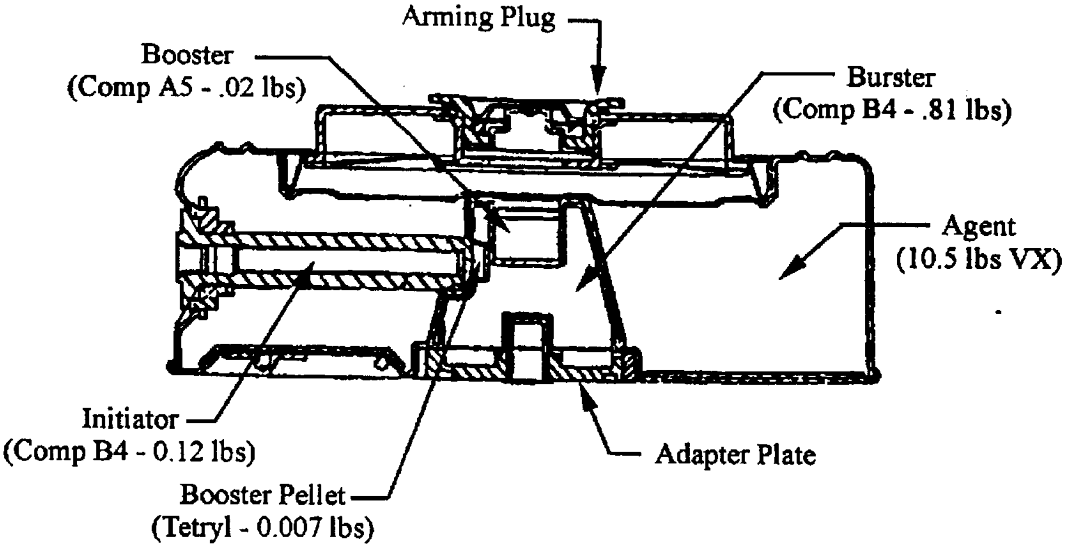
Booster
lead charge - 11.9 gm RDX
pellet booster - 72.6 mg RDX

Detonator	
lead styphnate	8 mg
lead azide	4 mg
barium nitrate	4 mg
antimony sulfide	3 mg
tetracene	1 mg
lead azide	130 mg
RDX	62.72 mg

Propellant - M28 double base (19.3 lbs)

Nitrocellulose	60%
Nitroglycerin	23.8%
Triacetin	9.9%
Dimethylphthalate	2.6%
Lead stearate	2.0%
2-Nitrodiphenylamine	1.7%

1345-K257 MINE, AGENT M23 VX



1345-00-542-1580 VX M23

M23 Land mine

The M23 land mine is a 13 inch diameter and 5 inch high munition filled with 10.5 pounds of VX. The mine weighs 22.75 pounds unfuzed. The mine consists of a body, a conical burster, and a side initiator charge. The M603 fuzes for the mines are packaged separately within the drums used for storage and shipping.

The body consists of a top section, a bottom cover, a pressure plate, springs, an arming plug, and a burster adapter. The top section and bottom cover, both made from low carbon steel, are joined by copper brazing at two circumferential joints to form the agent reservoir. It is important to note that the bottom cover has a reinforcing plate spot welded to its interior side, that forms a seam that will retain chemical agent and residue. The burster adapter is brazed to the side wall of the top section of the body. The pressure plate and springs are installed in the top of the mine and the arming plug is screwed into the pressure plate.

The conical burster assembly consists of a plastic cone filled with 370 grams of Composition B4 and two boosters. A tetryl booster pellet is mounted in the side of the cone and secured with adhesive tape. Another booster containing Composition A5 (98.0% min RDX / 1.6% min stearic acid) is placed in a well in the top of the cone and secured by pressing in a steel retainer. The conical burster is installed in the mine by placing it in the well in the bottom of the body. This burster is secured in the mine by a fuse well plate, which screws into the mine. The drawing package shows that this plate was initially made from steel and installed with a torque of 360 inch pounds (in lbs). A revision changed the plate material to plastic and lowered the installation torque to 160 to 180 in lbs. Land mines of both designs are in the stockpile.

The side initiator charge consists of a low carbon steel tube filled with explosive. The tube is finished with priming paint on both the exterior and interior. The original drawing specified tetryl pellets for the explosive, but revision B changed the explosive to Composition B4. It is not known whether any tetryl pellet side initiators are in the stockpile. The initiator charge is placed inside a burster tube, which is closed on one end, and secured with a snap ring. The VX agent is added to the mine, and then the burster tube is screwed into the burster adapter on the side of the mine body to seal in the agent. The installation torque for the burster tube is 75 to 100 ft-lbs.

The energetic components of the M603 fuze are as follows:

Fuze

Detonator			
	Upper Charge		89 mg
		Potassium Chlorate	53%
		Antimony Sulfide	17%
		Lead Thiocyanate (Sulphocyanate)	25%
		Lead Azide	5%
	Intermediate Charge		250 mg
		Lead Azide	100%
	Lower Charge		120 mg
		RDX	100%

DESCRIPTION OF MUNITIONS

Munition	Nominal Dimensions		Total Weight (lbs)	Fill Agent	Agent Weight (lbs)	Burster Explosive		Supplementary Charge	
	Diameter	Length (in)				Material	Weight (lbs)	Material	Weight (lbs)
Mortar, M2	4.2-in	21	25	HD	6	Tetryl	0.14	--	---
Mortar, M2	4.2-in	21	25	HT	5.8	Tetryl	0.14	--	---
Mortar, M2A1	4.2-in	21	25	HD	6	Tetryl	0.14	--	---
Projectile, M60	105 mm	19.6	38.8	HD	3	Tetrytol	0.26	--	---
Projectile, M360	105 mm	19.7	35.6	GB	1.6	Tetrytol	1.1	--	---
Projectile, M360	105 mm	19.7	35.6	GB	1.6	Comp B4	1.1	--	--
Projectile, M104	155 mm	26.8	95.1	H	11.7	Tetrytol	0.41	--	---
Projectile, M104	155 mm	26.8	95.1	HD	11.7	Tetrytol	0.41	--	---
Projectile, M110	155 mm	26.8	94.6	H	11.7	Tetrytol	0.41	--	---
Projectile, M110	155 mm	26.8	94.6	HD	11.7	Tetrytol	0.41	--	---
Projectile, M121	155 mm	26.7	97.2	GB	6.5	Tetrytol	2.7	--	---
Projectile, M121A1	155 mm	27	98.9	GB	6.5	Comp B4	2.45	TNT	0.3
Projectile, M121A1	155 mm	27	98.9	VX	6	Comp B4	2.45	TNT	0.3
Projectile, M122	155 mm	26.7	97.2	GB	6.5	Tetrytol	2.7	--	---
Projectile, M426	8-in	35.1	199	GB	14.5	Comp B4	7	TNT	0.3
Projectile, M426	8-in	35.1	199	VX	14.5	Comp B4	7	TNT	0.3
Rocket, M55	115 mm	78	57	VX	10	Comp B	3.2	--	---
Rocket, M55	115 mm	78	57	GB	10.7	Comp B	3.2	--	---
Rocket, M55	115 mm	78	57	VX	10	Tetrytol	3.2	--	---
Rocket, M55	115 mm	78	57	GB	10.7	Tetrytol	3.2	--	---
Mine, M23	13-in	5-in (ht)	22.75	VX	10.5	Comp B4	0.81	--	---

Tetrytol - 70% Tetryl / 30% TNT

Comp B - 60% RDX / 39% TNT / 1% Wax

Comp B4 - 60% RDX / 39.5% TNT / .5% Calcium Silicate

STOCKPILE by
National Stock Number

NSN	Munition	Anniston	Blue Grass	Johnston Island	Pine Bluff	Pueblo	Tooele	Umatilla
1320005677909	GB M121	--	--	--	--	--	32,726	--
1320005297346	GB M121	--	--	311	--	--	--	--
1320001437009	GB M121A1	--	--	12	--	--	--	--
1320008924186	GB M121A1	3,600	--	6,063	--	--	34,959	47,406
1320005299033	GB M122	6,000	--	--	--	--	21,456	--
1315002038985	GB M360	53,400	--	47,735	--	--	119,400	--
1315005677906	GB M360	26	--	--	--	--	679,303	--
1315010821234	GB M360	20,614	--	--	--	--	--	--
1320007636879	GB M426	16,026	3,977	13,020	--	--	--	14,246
1340007161450	GB M55	42,738	51,716	--	90,231	--	17,353	91,375
1320009650704	H M104	--	--	--	--	--	10,281	--
1320003011824	H M110	--	--	--	--	--	33	--
1320005297353	H M110	--	15,492	--	--	--	44,349	--
1320000284348	HD M104	--	--	--	--	26	--	--
1320005297350	HD M104	--	--	--	--	33,036	--	--
132000JI10001	HD M104	--	--	109	--	--	--	--
1320000963067	HD M110	--	--	--	--	68	--	--
1320005297352	HD M110	17,643	--	5,670	--	266,424	--	--
1315000285018	HD M2/M2A1	--	--	--	--		978	--
1315000285027	HD M2/M2A1	75,360	--	43,660	--	76,722	--	--
1315000284829	HD M60	2,500	--	36	--	382,575	--	--
1315003226365	HD M60	20,564	--	10	--	843	--	--
1315000285024	HT M2	183,552	--	--	--	20,384	62,590	--
1320007562888	VX M121A1	139,581	12,816	42682	--	--	53,216	32,313
1345005421580	VX M23	44,131	--	13,302	9,378	--	22,690	11,685
1320007636878	VX M426	--	--	13,591	--	--	--	3,752
1320008924306	VX M426	--	--	928	--	--	--	--
1340007243567	VX M55	35,636	17,733	--	19,582	--	3,966	14,513

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APPENDIX B:

CHEMICAL WEAPONS CONVENTION SCHEDULE OF CHEMICALS

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FOREWORD

This document provides a list of Schedule 1, 2, and 3 Compounds, as identified per the Chemical Weapons Convention. These schedules include toxic chemicals (the agents themselves) and chemical agent precursors. The information provided identifies the parent agent for which toxic chemicals and precursors are associated. The information contained in this appendix is based on the information provided in Appendix J2 of the following reference:

> U.S. Army, 1997, *Assessment of Technologies for Assembled Chemical Weapon Demilitarization*, Solicitation Number DAAM01-97-R-0031, U.S. Army Chemical and Biological Defense Command, Aberdeen Proving Ground, Md., July 28.

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APPENDIX B:

CHEMICAL WEAPON CONVENTION SCHEDULE OF CHEMICALS

Schedule 1	**Relationship**[1]
A. Toxic chemicals:	
(1) O-Alkyl (<C10, incl. cycloalkyl) alkyl (Me, Et, n-Pr or i-Pr)-phosphonofluoridates e.g., Sarin: O-Isopropyl methylphosphonofluoridate (107-44-8) Soman: O-Pinacolyl methylphosphonofluoridate (96-64-0)	GB and GD
(2) O-Alkyl (<C10, incl. cycloalkyl) N,N-dialkyl (Me, Et, n-Pr or i-Pr)phosphoramidocyanidates e.g., Tabun: O-Ethyl N,N-dimethyl phosphoramidocyanidate (77-81-6)	GA
(3) O-Alkyl (H or <C10, incl. cycloalkyl) S-2-dialkyl (Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonothiolates and corresponding alkylated or protonated salts e.g., VX: O-Ethyl S-2-diisopropylaminoethyl methyl phosphonothiolate (50782-69-9)	VX
(4) Sulfur mustards: 2-Chloroethylchloromethylsulfide (2625-76-5) Mustard gas: Bis(2-chloroethyl)sulfide (505-60-2) Bis(2-chloroethylthio)methane (63869-13-6) Sesquimustard: 1,2-Bis(2-chloroethylthio)ethane (3563-36-8) 1,3-Bis(2-chloroethylthio)-n-propane (63905-10-2) 1,4-Bis(2-chloroethylthio)-n-butane (142868-93-7)	H, HD, T, Q

---

[1] Relationship indicates what agent(s) the chemical is or is associated with. Only GB, VX, and H/HD/HT are part of the assembled chemical weapons (ACW) stockpile at Pueblo Chemical Depot (PCD), Pine Bluff Arsenal (PBA), Blue Grass Army Depot (BGAD), or Anniston Army Depot (ANAD).

Schedule 1 Toxic Chemicals (Cont.)	**Relationship[1]**
1,5-Bis(2-chloroethylthio)-n-pentane (142868-94-8)	
Bis(2-chloroethylthiomethyl)ether (63918-90-1)	
O-Mustard: Bis(2-chloroethylthioethyl)ether (63918-89-8)	
(5) Lewisites:	L1, L2, L3
Lewisite 1: 2-Chlorovinyldichloroarsine (541-25-3)	
Lewisite 2: Bis(2-chlorovinyl)chloroarsine (40334-69-8)	
Lewisite 3: Tris(2-chlorovinyl)arsine (40334-70-1)	
(6) Nitrogen mustards:	HN1, HN2 HN3
HN1: Bis(2-chloroethyl)ethylamine (538-07-8)	
HN2: Bis(2-chloroethyl)methylamine (51-75-2)	
HN3: Tris(2-chloroethyl)amine (555-77-1)	
(7) Saxitoxin (35523-89-8)	
(8) Ricin (9009-86-3)	
B. Precursors:	
(9) Alkyl (Me, Et, n-Pr or i-Pr) phosphonyldifluorides	G-Agents
e.g., DF: Methylphosphonyldifluoride (676-99-3)	
(10) O-Alkyl (H or <C10, incl. cycloalkyl) O-2-dialkyl (Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonites and corresponding alkylated or protonated salts	V-Agents
e.g., QL: O-Ethyl O-2-diisopropylaminoethyl methylphosphonite (57856-11-8)	
(11) Chlorosarin: O-Isopropyl methylphosphonochloridate (1445-76-7)	GB
(12) Chlorosoman: O-Pinacolyl methylphosphonochloridate (7040-57-5)	GD

Schedule 2	**Relationship**[2]
A. Toxic chemicals:	
(1) Amiton: O,O-Diethyl S-[2-(diethylamino)ethyl] phosphorothiolate (78-53-5) and corresponding alkylated or protonated salts	Amiton
(2) PFIB: 1,1,3,3,3-Pentafluoro-2-(trifluoromethyl)-1-propene (382-21-8)	PFIB
(3) BZ: 3-Quinuclidinyl benzilate (*) (6581-06-2)	BZ
B. Precursors:	
(4) Chemicals, except for those listed in Schedule 1, containing a phosphorus atom to which is bonded one methyl, ethyl or propyl (normal or iso) group but not further carbon atoms, e.g., Methylphosphonyl dichloride (676-97-1) Dimethyl methylphosphonate (756-79-6) Exemption: Fonofos: O-Ethyl S-phenyl ethylphosphonothiolothionate (944-22-9)	G/V-Agents
(5) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) phosphoramidic dihalides	V-Agents
(6) Dialkyl (Me, Et, n-Pr or i-Pr) N,N-dialkyl (Me, Et, n-Pr or i-Pr)-phosphoramidates	V-Agents
(7) Arsenic trichloride (7784-34-1)	Lewisite
(8) 2,2-Diphenyl-2-hydroxyacetic acid (76-93-7)	GF
(9) Quinuclidin-3-ol (1619-34-7)	BZ
(10) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) aminoethyl-2-chlorides and corresponding protonated salts	V-Agents

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[2] Relationship indicates what agent(s) the chemical is or is associated with. Only GB, VX, and H/HD/HT are part of the ACW stockpile at PCD, PBA, BGAD or ANAD. The Schedule 2 compounds are or could be used in the manufacture of the agent (toxic chemical) and the Chemical Weapons Convention (CWC) restricts their distribution in commerce. Schedule 2 compounds are not necessarily toxic compounds.

Schedule 2 Precursors (Cont.)	**Relationship[2]**
(11) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) aminoethane-2-ols and corresponding protonated salts	V-Agents
Exemptions: N,N-Dimethylaminoethanol (108-01-0) and corresponding protonated salts N,N-Diethylaminoethanol (100-37-8) and corresponding protonated salts	
(12) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) aminoethane-2-thiols and corresponding protonated salts	V-Agents
(13) Thiodiglycol: Bis(2-hydroxyethyl)sulfide (111-48-8)	H, HD, HT
(14) Pinacolyl alcohol: 3,3-Dimethylbutan-2-ol (464-07-3)	GD

Schedule 3	**Relationship**[3]
A. Toxic chemicals:	
(1) Phosgene: Carbonyl dichloride (75-44-5)	None
(2) Cyanogen chloride (506-77-4)	None
(3) Hydrogen cyanide (74-90-8)	None
(4) Chloropicrin: Trichloronitromethane (76-06-2)	None
B. Precursors:	
(5) Phosphorus oxychloride (10025-87-3)	G/V-Agents
(6) Phosphorus trichloride (7719-12-2)	G/V-Agents
(7) Phosphorus pentachloride (10026-13-8)	G/V-Agents
(8) Trimethyl phosphite (121-45-9)	G/V-Agents
(9) Triethyl phosphite (122-52-1)	G/V-Agents
(10) Dimethyl phosphite (868-85-9)	G/V-Agents
(11) Diethyl phosphite (762-04-9)	G/V-Agents
(12) Sulfur monochloride (10025-67-9)	Mustard
(13) Sulfur dichloride (10545-99-0)	Mustard
(14) Thionyl chloride (7719-09-7)	Mustard
(15) Ethyldiethanolamine (139-87-7)	V-Agents
(16) Methyldiethanolamine (105-59-9)	V-Agents
(17) Triethanolamine (102-71-6)	V-Agents

---

[3] Relationship indicates what agent(s) the chemical is or is associated with. Only GB, VX, and H/HD/HT are part of the ACW stockpile at PCD, PBA, BGAD, or ANAD. The Schedule 3 compounds could be used in the manufacture of the agent (toxic chemical), but the CWC does not restrict their use in commerce. Schedule 3 compounds are not necessarily toxic compounds.

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APPENDIX C:

CHEMICAL AGENTS: PHYSIOCHEMICAL PROPERTIES AND TOXICITY INFORMATION

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FOREWORD

This document provides general background information on each of the chemical agents contained in assembled chemical weapons maintained in the unitary chemical stockpile. For each chemical, relevant background information, physiochemical properties, and toxicological information are reviewed. The following chemicals are included in this document:

GB
VX
HD/H
HT
T

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CONTENTS

TABLES

NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this appendix. Some acronyms used in tables are defined in the respective tables only.

AChE	acetylcholinesterase
CAS	Chemical Abstracts Service
CHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
ChE	cholinesterase
Ct	concentration x time
d	day(s)
DA	U.S. Department of the Army
^oC	degree(s) Celsius
g	gram(s)
GB	sarin, O-isopropyl methylphosphonofluoridate
µg	microgram(s)
H	sulfur mustard (Levinstein process, undistilled), bis(2-chloroethyl) sulfide
HD/H	sulfur mustard or bis(2-chloroethyl) sulfide (unspecified purity)
HD	sulfur mustard (distilled), bis(2-chloroethyl) sulfide
HT	mixture of mustard (HD) and T-mustard (T)
ICt_{50}	concentration x time that is incapacitating to 50% of an exposed population
K_a	acid dissociation constant
kg	kilogram(s)
K_H	Henry's Law constant
K_{oc}	organic carbon partition coefficient
K_{OW}	octanol/water partition coefficient
kPa	kilopascal(s)
L	liter(s)
LC_{50}	concentration lethal to 50% of an exposed population
LCt_{50}	concentration x time lethal to 50% of an exposed population
LD_1	dose lethal to 1% of an exposed population
LD_{50}	dose lethal to 50% of an exposed population
LD_{lo}	lowest dose causing a lethal effect
LOAEL	lowest observed adverse effects level
M	molar
m^3	cubic meter(s)
mg	milligram(s)
min	minute(s)
mL	milliliter(s)
mol	mole(s)
MW	molecular weight
NOAEL	no observed adverse effect level

pK_a	negative logarithm of K_a (acid dissociation constant)
s	second(s)
T	T-mustard, bis(2-chloroethylthioethyl) ether
VX	O-ethyl S-(2-diisopropylaminoethyl) methylphosphonothiolate

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APPENDIX C:

CHEMICAL AGENTS:
PHYSIOCHEMICAL PROPERTIES AND TOXICITY INFORMATION

C.1 GB (Sarin or O-Isopropyl Methylphosphonofluoridate)
CAS Reg. No.[1] 107-44-8

$CH_3\text{-}P(=O)(O\text{-}CH[CH_3]_2)F$

C.1.1 Background

GB, an acutely toxic, relatively nonpersistent nerve agent, was developed and weaponized by Germany during World War II but was never used. It was subsequently adopted by the U.S. Armed Forces, produced in quantity, tested in laboratories and in the open air, and loaded in munitions. They were stockpiled but never used in combat.

C.1.2 Physicochemical Properties

The following pressure-temperature relationship was reported for GB (Samuel et al. 1983):

$$\log P\ (\text{torr}) = 7.48160 - 1{,}773.82/(227.9 + t[^\circ C]).$$

GB evaporates at about the same rate as water (HQ/DA, DN, AF 1990). It undergoes fairly rapid loss from unconfined soils by evaporation, leaching, and hydrolysis (Small 1984).

The hydrolytic half-life of GB is highest (the rate slowest) in the pH range of 4 to 6, about 160 hours at pH 5 and 25°C,[2] and decreases outside that range in either more alkaline or more acidic solutions (Clark 1989). The second order rate constant for hydroxyl-ion-catalyzed hydrolysis is (Demek et al. 1970):

$$\log k_2\ (M^{-1}\text{min}^{-1}) = 9.8507 - (1{,}985.4/t[K]).$$

---

[1] CAS Reg. No. = Chemical Abstracts Service Registry Number.

[2] Degrees Fahrenheit can be obtained with the conversion factor $(C^\circ \times 9/5) + 32$.

This relationship gives a value of 1,543 $M^{-1}min^{-1}$ at 25°C. Thus, the estimated rate constant at pH 10 is 0.1543 min^{-1}, and the half-life at that pH is 4 ½ minutes.

Small (1984) cited work by Puzderliski (1980) in an example of the rate of environmental disappearance of GB under relatively unfavorable conditions. GB in soil that was exposed to light rain at 0°C would disappear by a factor of 1,500 in 18 days. At 25°C, the time for this loss to occur was less than a day.

The strongly catalytic effect of aqueous hypochlorite ion on the hydrolysis of GB was studied by Epstein et al. (1956); they determined the second order rate constant to be 600 $M^{-1}min^{-1}$ at 25°C, with an acid dissociation constant (K_a) value of 4×10^{-8} for hypochlorous acid (HOCl). From these values, it can be estimated that the concentration of GB mixed with an excess of 3% commercial bleach at pH 8 would decrease over 1 millionfold in less than 5 seconds.

Environmentally relevant properties of GB are presented in Table C.1. Once released to the environment, GB persists for relatively short periods. Moreover, GB can be detoxified with mild chemical treatment.

TABLE C.1 Environmentally Relevant Properties of GB

Property	Data	Reference
Empirical formula	$C_4H_{10}FO_2P$	Not applicable
Molecular weight (MW), g/mol	140.1	Not applicable
Density, g/mL	1.0887/25°C	Samuel et al. 1983
Melting point, °C	-56.9	Samuel et al. 1983
Boiling point, °C	157.8	Samuel et al. 1983
Vapor pressure at 25°C, torr	2.94	Samuel et al. 1983
Log K_{ow}	0.15 (estimate)	Britton and Grant 1988
	0.299	Experimental value[a]
Aqueous solubility, g/L	Infinitely miscible	HQ/DA,DN,AF 1990
K_H, atm/m^3/mol	4.0×10^{-7}/25°C	Estimate[b]
Log K^{oc}	1.8 (estimate)	Small 1984
	1.54	Calculated[c]

[a] See U.S. Army Center for Health Promotion and Preventive (CHPPM) (1999).

[b] Based on estimated vapor pressure of 0.136 kPa for 0.1 mole fraction (ca. 3.34 M) of GB in water, K_H = 0.00134 atm/(3,340 mol/m^3) from Figure 2 of Preston and Starrock 1983.

[c] Derived from Log K_{ow} of 0.299, as shown above, using equation from Lyman et al. 1990.

C.1.3 Toxicity

The toxicity of GB varies, depending on the route of administration. The LCt_{50} (concentration × time that is lethal to 50% of an exposed population) for GB estimated for 70-kg humans breathing at the rate of 15 L/min is about 70 mg/min/m^3 (Edgewood Arsenal 1974). Assuming that GB is completely absorbed through the lungs, this value is equivalent to an oral LD_{50} (dose lethal to 50% of an exposed population) of about 15 µg/kg. Table C.2 shows the lethal effects of GB in experimental animals by different routes of exposure.

Like all nerve agents, GB exerts its effects through inhibition of the enzyme acetylcholinesterase (AChE), which is required for nerve and muscle function. Normally, AChE prevents accumulation of acetylcholine after its release as a chemical messenger in the nervous system. AChE inhibition adversely affects skeletal muscle, parasympathetic end organ, and central nervous system operation. Individuals poisoned by sufficient amounts of GB may show the following signs and symptoms soon after exposure (Edgewood Arsenal 1974; HQ/DA, DN, AF 1990):

- Difficulty in breathing, tightness of chest;
- Dimness of vision and pinpointing of the eye pupils;

TABLE C.2 Comparison of Some Toxicities of GB by Different Routes of Exposure in Different Species

Route	Type of Exposure	Species	Toxicity
Intravenous	LD_{50}[a]	Mouse	113 µg/kg
Intravenous	LD_{50}	Rat	39 µg/kg
Inhalation	LD_{50}	Mouse	5 mg/m^3/10 min
Subcutaneous	LD_{50}	Guinea pig	30 µg/kg
Subcutaneous	LD_{50}	Rat	103 µg/kg
Subcutaneous	LD_{50}	Rabbit	30 µg/kg
Intraperitoneal	LD_{50}	Rat	218 µg/kg
Intraperitoneal	LD_{50}	Mouse	420 µg/kg

[a] LD_{50} = dose lethal to 50% of an exposed population.

Source: Sweet (1987).

- Drooling and excessive sweating;
- Nausea;
- Vomiting, cramps, and loss of bladder/bowel control;
- Twitching, jerking, and staggering;
- Headache, confusion, drowsiness, coma, and convulsion; and
- Death.

An important characteristic that distinguishes the behavior of GB from other nerve agents is that cholinesterase (ChE) inhibited by GB can undergo spontaneous reactivation, whereas ChE inhibited by some of the other nerve agents rapidly ages to an inhibited form of the enzyme that is resistant to either spontaneous or therapeutic reactivation (Daniels 1990).

The number and severity of symptoms of GB poisoning depend on the quantity and route of entry of this nerve agent into the body, as well as the duration of exposure. When the eyes are exposed to the agent vapor, a prominent sign is pinpointing of the pupils. Dimness of vision results from the reduced amount of light entering the eyes. However, if exposure to the nerve agent is through the skin or by ingestion, the pupils may be normal or only slightly reduced in size. In this event, diagnosis must rely on other symptoms of nerve agent poisoning (HQ/DA, DN, AF 1990).

Respiratory exposure usually results in the onset of symptoms in 2 to 5 minutes; lethal doses kill in less than 15 minutes. Exposure through the eyes also produces a very rapid onset of symptoms (usually less than 2 to 3 minutes). Liquid agent in the eyes kills nearly as rapidly as respiratory exposure. Symptoms from skin absorption appear more slowly. Death from skin absorption may occur in 1 to 2 hours. Very small skin dosages sometimes cause local sweating and tremors (muscle twitching) but few other effects (HQ/DA, DN, AF 1990).

If a victim recovers from acute GB poisoning, the recovery will be complete unless anoxia and convulsions have gone unchecked so long that irreversible central nervous system damage has occurred (HQ/DA, DN, AF 1990).

Ninety-day subchronic toxicity test results for GB in male rats gave a lowest observed adverse effects level (LOAEL) of 0.075 mg/kg/d (5 days per week, adjusted to 0.054 mg/kg/d for 7 days per week) of agent administered by gavage. At the end of the first week of exposure, red blood cell cholinesterase decreased 38%. Other signs of toxicity were not observed at any of the dose levels (up to 300 μg/kg/d) (Bucci and Parker 1991).

C.2. VX [O-Ethyl S-(2-Diisopropylaminoethyl) Methylphosphonothioate] CAS Reg. No. 50782-69-9

$CH_3\text{-}P(=O)(OC_2H_5)(S\text{-}CH_2\text{-}CH_2\text{-}N[CH(CH_3)_2]_2)$

C.2.1 Background

Following World War II, Great Britain developed the nerve agent VX to circumvent respiratory protection. VX is fairly effective compared to other nerve agents, namely G agents. VX was subsequently adopted by the United States, produced in quantity, tested in laboratories and in the open air, and loaded in munitions that were stockpiled but never used in combat.

VX, which is dispersed as an aerosol because of its low volatility, is acutely toxic, highly effective by the percutaneous route (100 times as effective as GB [HQ/DA,DN,AF 1990]), and although more persistent than the G agents, is nevertheless relatively nonpersistent.

C.2.2 Physicochemical Properties

The following pressure-temperature relationship was reported for VX (Samuel et al. 1983):

$$\log P\ (\text{torr}) = 7.28100 - 2{,}072.10/(172.5 + t[^\circ C]).$$

VX, a good skin penetrant, is more persistent than G agents because of its low vapor pressure — its evaporation rate is about 1/1,500 that of water (HQ/DA, DN, AF l990). The pK_a of protonated VX at 25°C has been given as 8.60 (Epstein et al. 1974) or as 9.1 (Demek et al. 1970).

VX hydrolysis rates (Table C.3) tend to be slower (half-life longer) than those of the G agents; thus, at pH 10 and 25°C, the half-life of VX in water is 2,432 minutes (converted data from Epstein et al. [1974]), compared with 4½ minutes for GB. At pH 5 and 25°C, the half-life was reported as 2,342 hours (Clark 1989).

The hydrolytic reactions of VX can involve multiple pathways. Both rates and products depend on pH (Epstein et al. 1974; Yang et al. 1990, 1992, 1993, 1994; Szafraniec et al. 1993), temperature, and VX concentration (Yang et al. 1994). VX is not subject to acid-catalyzed hydrolysis but does undergo water- and hydroxyl-ion-catalyzed hydrolysis.

Studies in the Netherlands on the degradation of VX in soil involved application of 200 mg/kg of VX to soil (Verweij and Boter 1976; Kaaijk and Frijlink 1977). After three weeks, only 0.1% of the applied VX was detectable. Thus, it may be concluded that VX is not chemically stable in soil.

The chemistry of decontamination of VX with chlorine bleaches is complex; however, VX is effectively detoxified by these oxidants (Yang et al. 1992, 1994). Environmentally relevant physicochemical properties of VX are presented in Table C.4.

TABLE C.3 Hydrolysis Half-Lives for VX

pH	Half-Life (hours @ 25°C)
2.0	2,520
4.0	2,257
6.0	2,381
7.0	996
8.0	184
9.0	63
10.0	40.5
11.0	15
12.0[a]	2.5
12.65	0.525
12.9	0.279
13.5	0.0529

[a] Approximately 0.01 M NaOH.

Source: Epstein et al. (1974).

Once released to the environment, VX would be expected to persist for moderate periods (weeks to months). The most effective way to detoxify VX would be with hypochlorite-containing bleach.

It may be concluded that VX would persist in the environment for longer periods than G agents, but would decompose completely in a matter of weeks or months.

C.2.3 Toxicity

As with the G agents, VX exerts its physiologic effects through inhibition of the enzyme AChE. VX is especially effective percutaneously. Individuals poisoned by ingestion of VX may show the following signs and symptoms (Edgewood Arsenal 1974; HQ/DA, DN, AF 1990):

- Difficulty in breathing and tightness of chest;
- Dimness of vision and pinpointing of the eye pupils;
- Drooling and excessive sweating;

TABLE C.4 Environmentally Relevant Properties of VX

Property	Data	Reference
Empirical formula	$C_{11}H_{26}NO_2PS$	Not applicable
Molecular weight (MW), g/mol	267.38	Not applicable
Density, g/mL	1.0083/25°C	Samuel et al. 1983
Melting point, °C	-50	Samuel et al. 1983
Boiling point, °C	298.4	Samuel et al. 1983
Vapor pressure, torr	6.2×10^{-4}/25°C	Samuel et al. 1983
Log K_{ow}	2.09 (estimate)	Small 1984
Aqueous solubility, g/L	30/25°C	Edgewood Arsenal 1974
K_H, atm/m^3/mol	7.2×10^{-9}/25°C	Estimated from the equation for log P (see p. C.9)
Log K_{oc}	1.18	Sage and Howard 1989

- Nausea, vomiting, cramps, and loss of bladder/bowel control;

- Twitching, jerking, and staggering;

- Headache, confusion, drowsiness, coma, and convulsion; and

- Death.

The LCt_{50} value for VX, estimated for humans breathing at the rate of 15 L/min, is 30 mg/min/m^3 (Edgewood Arsenal 1974). If the compound is completely absorbed, the equivalent oral LD_{50} would be 0.0064 mg/kg. According to Michel et al. (1962), the rat oral LD_{50} for VX is 0.178 mg/kg.

Because VX has such a low volatility, liquid droplets on the skin do not evaporate as do uncovered droplets of GB; thus, effective percutaneous absorption can take place. Thus, by this route, VX is estimated to be more than 100 times as toxic as GB to man (Edgewood Arsenal 1974).

If a victim recovers from acute VX poisoning, the recovery will be complete unless anoxia and convulsions have gone unchecked long enough to cause irreversible central nervous system damage (HQ/DA, DN, AF 1990).

In a 90-day (subchronic) toxicity test conducted for VX with rats, the LOAEL was 0.25 µg/kg/d (5 days per week, adjusted to 0.179 µg/kg/d for 7 days per week) of agent administered by subcutaneous injection. The only adverse effect at this dosage was a decrease of the red blood cell cholinesterase level to a low of 33% in males at 60 days and 48% in females at 30 days (Goldman et al. 1988).

C.3 HD/H [Sulfur Mustard or Bis(2-Chloroethyl) Sulfide] CAS Reg. No. 505-60-2

$Cl\text{-}CH_2\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}Cl$

C.3.1 Background

Mustard gas (H/HD, H is undistilled mustard; HD refers to distilled mustard) was first synthesized in 1822, but its toxicity was only discovered in 1860. Germany first used H during World War I (July 1917) in Belgium; it was soon adopted, produced in large amounts, and used by the Allied powers (Rosenblatt et al. 1975). H and HD were produced and stockpiled by both sides during World War II, but they were not used in that conflict.

H differs from HD in that H contains certain impurities normally absent from HD; however, there is no standard composition for H. Production grade H (manufactured by the Levinstein process) was a mixture of mustard with sulfur and various impurities (Fuson et al. 1946). The H was distilled to improve the agent's storage stability, thereby separating HD from a sulfur-rich waste sludge. Virtually all available physicochemical information on what is commonly known as "mustard gas" has been determined on the basis of relatively pure HD.

C.3.2 Physicochemical Properties

Table C.5 lists environmentally relevant properties of HD. In addition to the data in Table C.5, the following pressure-temperature relationship was reported for HD (Penski 1993):

$$\log P\ (\text{torr}) = 7.4749753 - 1{,}940.711/(204.6712 + t[°\text{C}]).$$

HD has a low solubility in water and a low rate of solution. For these reasons, HD is difficult to decontaminate by aqueous hydrolysis despite the relatively high first-order rate constant of the reaction once the HD is in solution.

Despite the rapidity with which the hydrolysis reaction occurs, in quiescent conditions there is a tendency for HD to polymerize at the HD/water interface, thus interfering with the transfer of HD to the aqueous phase and thus further shielding the bulk agent from hydrolysis reactions (MacNaughton and Brewer 1994). However, with adequate mixing, HD can be readily detoxified.

TABLE C.5 Environmentally Relevant Properties of HD

Property	Data	Reference
Empirical formula	$C_4H_8Cl_2S$	Not applicable
Molecular weight (MW), g/mol	159.08	Not applicable
Density, g/mL	1.2685/25°C	Samuel et al. 1983
Melting point, °C	14.445	Penski 1993
Boiling point, °C	217.5	Samuel et al. 1983
Vapor pressure, torr	0.082/22°C[a]	Samuel et al. 1983
	0.1059/25°C[a]	Samuel et al. 1983
Log K_{ow}	1.37	EPA 1986
Aqueous solubility, g/L	0.92/22°C	Edgewood Arsenal 1974
K_H, atm/m^3/mol	2.57×10^{-5}	Sage and Howard 1989
Log K_{oc}	2.0-2.1	Sage and Howard 1989

[a] Calculated from the equation for log P (see p. C-9).

Small (1984) cited work by Puzderliski (1980) in an example of the rate of environmental disappearance of HD under relatively unfavorable conditions. HD in soil that was exposed to light rain at 0°C would disappear by a factor of 1,500 in three months. At 25°C, the time for this to occur was about two days.

The sulfur moiety of HD is readily subject to decontamination by oxidation with various forms of hypochlorite-containing materials, such as bleach solution (approximately 5% aqueous sodium hypochlorite), chlorinated lime, or "high-test hypochlorite" (HTH) (Yang et al. 1992).

If released to the environment in low concentrations, HD would not be expected to persist for long, but sizable masses could remain, more or less encapsulated, for considerable periods. HD can be effectively decontaminated with hypochlorite.

C.3.3 Toxicity

HD is a vesicant (blister agent), as well as an alkylating agent producing cytotoxic effects on the hematopoietic (blood-forming) tissues. Its primary effects are on the skin and eyes, although it is also toxic by inhalation or ingestion (Edgewood Arsenal 1974). Table C.6 shows the lethal effects of HD in experimental animals by different routes of administration.

The human respiratory LCt_{50} for HD is 1,500 mg/min/m^3 (Edgewood Arsenal 1974; HQ/DA, DN, AF 1990). The percutaneous LCt_{50} is estimated as 10,000 mg/min/m^3 (HQ/DA, DN, AF 1990). The estimated human oral LD_{50} for HD is 0.7 mg/kg (Edgewood Arsenal 1974);

TABLE C.6 Comparison of Some Toxicities of HD by Different Routes in Different Species

Route	Type of Exposure	Species	Toxicity
Intravenous	LD_{50}	Mouse	8,600 µg/kg
Intravenous	LD_{50}	Rat	700 µg/kg
Inhalation	LD_{50}	Mouse	120 mg/m^3/20 min
Subcutaneous	LD_{50}	Rat	1,500 µg/kg
Subcutaneous	LD_{50}	Rabbit	20,000 µg/kg
Subcutaneous	LD_{50}	Mouse	20,000 µg/kg

Source: Sweet (1987).

this estimate seems low in view of the intragastric LD_{50} of 17 mg/kg for rats (Edgewood Arsenal 1974). The human percutaneous LD_{50} is estimated as 100 mg/kg (Safety Office, undated). For percutaneously exposed (but masked) personnel, an air Ct (concentration x time) of as little as 1,000 mg/min/m^3 can be incapacitating (Edgewood Arsenal 1974; HQ/DA, DN, AF 1990). The human respiratory ICt_{50} (concentration x time that is incapacitating to 50% of a population) for this agent is 150 mg/min/m^3 (HQ/DA, DN, AF 1990). Eye injury from HD occurs at an air Ct of about 100 mg/min/m^3 (Edgewood Arsenal 1974). Effects of HD are not immediately manifest; the latent period for appearance of ocular symptoms is 4 to 12 hours after mild exposure, 3 to 6 hours after moderate exposure, and 1 to 3 hours after severe exposure (Edgewood Arsenal 1974).

In acute (single-episode) exposures to HD vapors, the eyes are especially sensitive. Symptoms of mild exposure (after a latent period) consist of tearing and a sensation of "sand" in the eyes; the conjunctiva and lids becoming swollen and fluid-filled. Higher exposures bring on blepharospasm (inability to keep the eyes open), blurring of vision, mucoserous discharge, and other symptoms of ocular irritation. At the highest exposures, there is also headache, deep ocular pain, ulceration, necrosis, and dense corneal opacification. Convalescence can take as long as several months (Edgewood Arsenal 1974).

Reaction to acute skin exposure to HD is first manifested (after some delay) by gradual reddening of the skin, as if by sunburn, accompanied by itching and mild burning. This is followed by blistering; pinpoint lesions form, enlarge, and coalesce to large translucent yellowish blisters. If the blisters do not rupture, they are resorbed in about a week. Mustard burns of the skin are usually followed by a persistent brown pigmentation, except at the site of vesication, which may be depigmented. In addition to surface effects, high levels of HD vapor would be absorbed through the skin into the body to cause systemic effects. These effects may include anorexia, nausea, vomiting, depression, and fever (Edgewood Arsenal 1974).

Respiratory tract lesions caused by acute exposure to HD develop slowly over several days. Symptoms begin with hoarseness, which may progress to aphonia (loss of voice), cough, fever, and dyspnea (shortness of breath). Incidence of bronchopneumonia is high. Convalescence is slow, and coughing may persist for a month or longer (Edgewood Arsenal 1974).

Ingestion of food or water contaminated with liquid HD produces nausea, vomiting, pain, diarrhea, and prostration (Edgewood Arsenal 1974).

The eyes of workers exposed to HD for over two months showed low-grade conjunctival infection, reduced corneal sensitivity, and staining or pigmentation of the corneal epithelium (Edgewood Arsenal 1974).

Repeated skin exposure may lead to hypersensitivity of the skin to HD. Sensitization is followed by a more rapid onset of symptoms upon re-exposure to low levels of HD, as well as by the development of a dermatitis similar to that from poison ivy (Edgewood Arsenal 1974). Exposures of munitions plant workers to HD for three weeks to six months led these men to seek treatment for respiratory distress. Typically, males developed some or all of the following symptoms: red eyes, photophobia, lacrimation, impaired vision, blepharospasm, loss of taste and smell, nose bleed, sore throat, chest pain, wheezing, and dyspnea. Furthermore, repeated exposure to HD led to lingering bronchitis, bronchial asthma, hoarseness, aphonia, and hypersensitivity to smoke, dust, and fumes (Panel on Cholinesterase Reactivator Chemicals et al. 1984).

HD is a carcinogen via inhalation in animals and humans, as well as a mutagen (Panel on Cholinesterase Reactivator Chemicals et al. 1984). An upper bound (95% confidence limit) unit inhalation cancer risk of 8.5×10^{-2} $\mu g/m^3$ has been calculated for HD (Koppikar et al. 1991).

In a 21-week study of rats, HD was dissolved in sesame oil and administered by gavage (stomach tube), giving an LOAEL of 0.022 mg/kg/d. (This average level was obtained by dividing the total dose of HD at the lowest dose level by 147 days.) The critical effect was epithelial hyperplasia of the forestomach, an anatomical feature not present in humans (Sasser et al. 1989a).

C.4 HT [Mustard (HD)-T-Mustard (T) Mixture]
CAS Reg. No. Not Applicable

$$Cl\text{-}CH_2\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}Cl$$

$$+$$

$$Cl\text{-}CH_2\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}O\text{-}CH_2\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}Cl$$

C.4.1 Background

The usual HT mixture is 60% HD and 40% T by weight (T-mustard is discussed in Section C.5). Pure HD freezes at $14.4^{o}C$ and pure T freezes at $9.0^{o}C$ (Samuel et al. 1983), while the 60/40 eutectic mixture freezes at $0^{o}C$ to $1.3^{o}C$ (HQ/DA, DN, AF 1990). The mixture is said to be more stable and more persistent than HD (HQ/DA, DN, AF 1990). The U.S. military stockpile includes HT in munitions.

C.4.2 Physicochemical Properties

The vapor pressure of HT is 0.104 torr, and the density is 1.269 g/mL at $25^{o}C$ (HQ/DA, DN, AF 1990). The mixture boils above $228^{o}C$. It is barely soluble in water and dissolves very slowly. However, once dissolved, it hydrolyzes fairly rapidly. Like HD, HT can be decontaminated with various hypochlorite mixtures (HQ/DA, DN, AF 1990).

C.4.3 Toxicity

The main military reason for using the HT mixture is to deliver liquid HD to the target at temperatures below the freezing point of that compound. HT skin contamination produces strong, but delayed, blistering, as well as eye irritation (HQ/DA, DN, AF 1990). (See Section C.3.3 for a discussion of the toxicity of HD.)

C.5 T [T-Mustard or Bis(2-Chloroethylthioethyl) Ether]
CAS Reg. No. 63918-89-8

$Cl\text{-}CH_2\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}O\text{-}CH_2\text{-}CH_2\text{-}S\text{-}CH_2\text{-}CH_2\text{-}Cl$

C.5.1 Background

T is a mustard-like vesicant (blister agent). It is apparently not a normal constituent of either H or HD (Rosenblatt et al. 1996). It has either been manufactured for the purpose of mixing it with HD to produce the vesicant agent HT (see Section C.4) or was generated as a co-product with HD by modifying the HD synthetic process. When it exists, T is always found with HD. T is in the U.S. stockpile, but only as a component of HT.

C.5.2 Physicochemical Properties

The following pressure-temperature relationship was reported (Samuel et al. 1983) for liquid T:

$$\log P \text{ (torr)} = 9.53000 - 4{,}191.00/T \text{ (K)}.$$

Table C.7 lists the environmentally relevant properties for T. It may be concluded that T is considerably less volatile than HD and represents no vapor threat, only a possible contact threat.

C.5.3 Toxicity

Mustard-like compounds such as T are vesicants (blister agents) as well as alkylating agents that produce cytotoxic effects on the hematopoietic (blood-forming) tissues. Their primary effects are on the skin and eyes, although they are also toxic by inhalation or ingestion (Edgewood Arsenal 1974). The inhalation LC_{50} for T in mice is 1,650 mg/m^3/10M (Sweet 1987).

TABLE C.7 Environmentally Relevant Properties of T

Property	Data	Reference
Empirical formula	$C8H_{16}Cl_2S_2$	Not applicable
Molecular weight (MW), g/mol	263.25	Not applicable
Density, g/mL	1.2362/25°C	Samuel et al. 1983
Melting point, ^oC	8.97	Samuel et al. 1983
Boiling point, ^oC	357	Samuel et al. 1983
Vapor pressure, torr	3.0×10^{-5}	Samuel et al. 1983
Log K_{ow}	0.68	Estimated from the equation for log P (see p. C-9).
Aqueous solubility, g/L	Practically insoluble	Safety Office undated

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APPENDIX D:

ENERGETIC COMPONENTS: PHYSIOCHEMICAL PROPERTIES AND TOXICITY INFORMATION

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FOREWORD

The purpose of this document is to provide general physicochemical properties and toxicity information for each of the energetic components in the assembled chemical weapons (ACW). Table D.1 lists all the types of munitions that are included in the ACW and their major components (i.e., agent, burster assembly, propellant, and fuze). Table D.2 lists all fuzes that are an integral part of the munitions or that are packaged with the munitions. The tables are followed by descriptions of each of the energetic materials associated with ACW, beginning with the energetic composites and followed by other components in alphabetical order.

The descriptions include the chemical name, Chemical Abstract Service Registry Number (CAS Reg. No.), chemical formula, background information, and physicochemical properties and toxicity information, to the extent that such information is available. In many cases, physiochemical property and toxicity information for the energetic compounds was not readily available. Whatever information was found is presented here. Blanks in the specific energetic tables indicate that no data were found.

Note that energetic components could contain small amounts of impurities; such impurities are not described in this document.

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CONTENTS

CONTENTS (CONT.)

TABLES

TABLES (Cont.)

NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this appendix. Some acronyms used in tables are defined in the respective tables only.

ACW	assembled chemical weapons
°C	degree(s) Celsius
CAS Reg. No.	Chemical Abstract Service Registry Number
cal	calorie(s)
cc	cubic centimeter(s)
d	day(s)
EPA	U.S. Environmental Protection Agency
g	gram(s)
GB	sarin, O-isopropyl methylphosphonofluoridate
H	sulfur mustard (levinstein process, undistilled), bis(2-chloroethyl) sulfide
HD	sulfur mustard (distilled) bis(2-chloroethyl) sulfide
HMX	cyclotetramethylenetetranitramine
in.	inch(es)
kcal	kilocalorie(s)
kg	kilogram(s)
L	liter(s)
LD_{50}	lethal dose to 50% of those exposed
LD_{LO}	lowest dose causing a lethal effect
MCL	maximum contaminant level
mg	milligram(s)
MIDAS	Munitions Items Disposition Action System
mL	milliliter(s)
mol	mole(s)
m^3	cubic meter(s)
mm	millimeter(s)
ppm	parts per million
RfD	reference dose
TD_{LO}	lowest dose causing a toxic effect
TLV	threshold limit value
VX	O-ethyl S-(2-diisopropylaminoethyl) methyl phosphonothiolate

TABLE D.1 Assembled Chemical Weapons

Munitions Type	Agent	Burster Assembly	Propellant	Fuze
Rocket, M55	GB or VX	M34 – Comp B4 M36 – Comp B4[a]	M28 Propellant - Nitrocellulose, Nitroglycerin, 2-nitrodiphenylamine, triacetin, lead stearate, dimethylphthalate M62 Igniter - Cellulose nitrate, magnesium powder, potassium perchlorate M2 Electric Squib - Lead Thiocyanate, potassium chlorate, carbon, Egyptian lacquer	M417[b]
Land Mine, M23	VX	M1 Activator – Potassium chlorate, lead thiocyanate, lead azide, tetryl M48 Initiator – Comp B4 M38 Burster – Comp B4 & tetryl M120 Booster – Comp A5	None	M603
Projectile, 155-mm			None	None
M104	HD	M6 – Tetrytol		
M110	H or HD	M6 – Tetrytol		
M121	GB	M37 – Tetrytol		
M121Al	GB or VX	M71 – Comp B4		
M122	GB	M37 – Tetrytol		
Projectile, 8-in., M426	GB or VX	M83 – Comp B4	None	None
Cartridge, 105-mm				
M60	HD	M5 – Tetrytol	M28A2 Primer - Black powder M1 Propellant - Nitrocellulose, lead carbonate, diphenylamine, di-nitrotoluene, dibutyl-phthalate	M57 & M51A1
M360	GB	M40 – Tetrytol or M40A1 – Comp B4	c	M508 &M557
Cartridge, 4.2-in.				
M2/M2A1 d	HT or HD	Tetryl	M6 Propellant - Nitro-cellulose, nitroglycerin, diethylphthalate, potassium nitrate, ethyl centralite M2 Igniter - nitrocellulose, nitroglycerin, ethyl centralite,	M8

[a] The burster may be either Composition B or tetrytol.

[b] Carbon, magnesium powder, and Egyptian lacquer, components associated with the electric squib and igniter for the M55 Rocket, are not described further in this document

[c] The propellant for the M60 and M360 is the same.

[d] The M2A1 only contains HD.

TABLE D.2 Fuze Components

Energetic Component	M8	M51A5	M57	M417	M508	M557	M603
Antimony sulfide	x	x	x	x	x	x	x
Barium nitrate				x			
Black powder						x	
Carborundum	x	x	x		x	x	
Lead azide	x	x	x	x	x	x	x
Lead styphnate				x			
Lead thiocyanate							x
Potassium chlorate	x	x	x		x	x	x
RDX				x			x
Tetracene				x			
Tetryl	x	x			x	x	

D.1 SENSITIVITY

One of the most important properties of energetic compounds is sensitivity. Sensitivity is related to the ability of an energetic component to ignite or explode following some type of initiating action, such as increased temperature or a shock. One of the more common methods of measuring sensitivity is by the impact test. The following discussion is relevant to the Bureau of Mines and Picatinny Arsenal apparatus.

Sensitivity to impact is expressed as the minimum height of fall of a given weight required to cause at least one explosion in 10 trials, or the minimum height of fall of a given weight to cause explosions in 50% of the trials. The Picatinny apparatus can be used for testing explosives having a very wide range of sensitivity. The Bureau of Mines apparatus, however, cannot cause the explosion of the most insensitive explosives and can be used only for testing explosives no less sensitive than TNT. Details of the apparatus and the impact test can be found in the U.S. Army's technical manual on military explosives (U.S. Army 1984).

D.2 ENERGETICS COMPONENTS

D.2.1 Composition B (mixture of RDX, TNT, and wax)

D.2.1.1 Background

Composition B refers to mixtures of approximately 59.5% RDX, 39.5% TNT, and 1.0% wax. Other portions of RDX and TNT mixtures are called cyclotols. High-quality castings usually are higher in RDX content because a TNT-rich section is removed from the top of the casting. The casting has a nominal formulation of 36% TNT, 63% RDX, and 1.0% wax (U.S. Army 1984). Composition B was used as burster material in the M55 rocket, the M23 land mine, the M121A1 155-mm projectile, and the 8-in. projectile. There is also a wax that is used in Composition B that is not described here.

D.2.1.2 Physicochemical Properties

RDX is slightly soluble in molten TNT, and the two compounds form a eutectic mixture that freezes at 79.0°C.[1] The theoretical maximum density of Composition B is 1.737 g/cc. Storage of Composition B at 75°C for 1 month causes no decrease in stability. Storage at 65°C for over a year causes no change in acidity, sensitivity to impact, or brisance. However, 5 months of such storage causes slight exudation. Composition B, therefore, is of a high order of chemical stability but should not be stored at too elevated a temperature because of physical instability at such temperatures. The impact sensitivity of Composition B is 14 in. using a 2-kg weight in the Picatinny Arsenal apparatus. It is 60 cc using a 2-kg weight in the Bureau of Mines apparatus (U.S. Army 1984).

D.2.1.3 Toxicity

See RDX and TNT.

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[1] Degrees Fahrenheit can be obtained with the conversion factor (C° × 9/5) + 32.

D.2.2 Composition B4 (mixture of RDX, TNT, and calcium silicate)

D.2.2.1 Background

Composition B4 is a combination of 60% RDX, 39.5% TNT, and 0.5% calcium silicate (U.S. Army 1984). It is used as a booster and/or burster in the M55 rocket, M23 land mine, M121A1 155-mm projectile, M426 8-in. projectile, and the M360 105-mm cartridge.

D.2.2.2 Physicochemical Properties

Similar to Composition B.

D.2.2.3 Toxicity

See RDX, TNT, and calcium silicate.

D.2.3 Composition A5 (mixture of RDX and stearic acid)

D.2.3.1 Background

Composition A5 is a mixture of approximately 98.5% RDX and 1.5% stearic acid, which is a desensitizer (U.S. Army 1984). Composition A5 is used as a booster in the M23 land mine.

D.2.3.2 Physicochemical Properties

Similar to RDX.

D.2.3.3 Toxicity

See RDX and stearic acid.

D.2.4 M6 Propellant

D.2.4.1 Background

The M6 propellant is a single-base propellant that is used with the M2 and M2A1 4.2-in. cartridge; however, not all of these cartridges in the stockpile are configured with the M6 propellant. It is a low-cost propellant that has a low flame temperature and low energy content.

D.2.4.2 Physicochemical Properties

M6 propellant is composed of 87% nitrocellulose, 10% dinitrotoluene, 3% dibutylphthalate, 1% diphenylamine, and small amounts (<1%) of residual ethyl alcohol and water (MIDAS 1999).

D.2.4.3 Toxicity

See nitrocellulose, dinitrotoluene, dibutylphthalate, and diphenylamine.

D.2.5 M28 Propellant

D.2.5.1 Background

The M28 Propellant is a double-base propellant used in the M55 rocket.

D.2.5.2 Physicochemical Properties

The M28 propellant is composed of 60% nitrocellulose, 23.8% nitroglycerine, 9.9% triacetin, 2.6 % dimethylphthalate, 2% lead stearate, and 1.7 % 2-nitrodiphenylamine (MIDAS 1999).

D.2.5.3 Toxicity

See nitrocellulose, nitroglycerine, triacetin, dimethylphthalate, lead stearate, and 2-nitrodiphenylamine.

D.2.6 Antimony Sulfide (Antimony trisulfide)
CAS Reg. No. 1345-04-6

S_6Sb_4

D.2.6.1 Background

Antimony sulfide is a component of the M51A1, M417, M508, M557, and the M603 fuzes.

D.2.6.2 Physicochemical Properties

Antimony sulfide is an orange-yellow powder.

D.2.6.3 Toxicity

Intraperitoneal LD_{50} in mice: 209 mg/kg (Sweet 1986).
TLV (as antimony), mg/m^3: 0.5 (ACGIH 1998).
Oral RfD (as antimony), mg/kg/d: 4×10^{-4} (EPA 1996).

TABLE D.3 Antimony Sulfide

Properties	Data	Reference
Empirical formula	S_6Sb_4	Chemfinder 1999
Molecular weight, g/mol	679.4	Chemfinder 1999
Density, g/cc	4.64 (black form) 4.12 (yellow-red form)	Fedoroff et al. 1983, Vol. 9, S 233
Melting point, °C	550	Chemfinder 1999
Boiling point, °C	about 1,150	Fedoroff et al. 1983, Vol. 9, S 233
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility, g/100cc	0.002@20°C	Lewis 1991
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.7 Barium Nitrate
CAS Reg. No. 10022-31-8

BaN_2O_6

D.2.7.1 Background

Barium nitrate is a component of the M417 fuze, which is an integral part of the M55 rocket.

D.2.7.2 Physicochemical Properties

Barium nitrate is crystalline and is a lustrous white.

D.2.7.3 Toxicity

Oral LD_{50} in rats: 255 mg/kg (Sweet 1986).
TLV (as barium), mg/m^3: 0.5 (ACGIH 1998).
Oral RFD (as barium), mg/kg/d: 7 x 10^{-2} (EPA 1996).
MCL, mg/L (as barium): 2 (EPA 1996).

TABLE D.4 Barium Nitrate

Properties	Data	Reference
Empirical formula	BaN_2O_6	Chemfinder 1999
Molecular weight, g/mol	261.3398	Chemfinder 1999
Density, g/cc	3,244 @23°C	Fedoroff et al. 1983, Vol. 2, B20
Melting point, °C	592	Chemfinder 1999
Boiling point, °C	Decomposes	Fedoroff et al. 1983, Vol. 2, B20
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility, g/100cc	5.02 @ 0°C 34.2 @ 100°C	Fedoroff et al. 1983, Vol. 2, B20
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.8 Black Powder

D.2.8.1 Background

Authorities differ on the origin of black powder, accrediting in turn the Chinese, Hindus, and Arabs. In 1249 AD, Roger Bacon, an English monk, recorded a formula for black powder: saltpeter (7 parts), carbon (4 parts), and sulfur (4 parts). Sulfur and carbon had been used in incendiary compositions for many centuries. Saltpeter (potassium nitrate) appears in nature but requires refining (U.S. Army 1984).

Black powder is a component of the M557 fuze, as a delay charge.

D.2.8.2 Physicochemical Properties

See potassium nitrate and sulfur.

D.2.8.3 Toxicity

See potassium nitrate and sulfur.

D.2.9 Calcium Silicate
CAS Reg. No. 1344-95-2

Ca_2O_4Si

D.2.9.1 Background

Calcium silicate is a component of Composition B4.

D.2.9.2 Physicochemical Properties

Calcium silicate is a white or slightly cream-colored, free-flowing powder.

TABLE D.5 Calcium Silicate

Properties	Data	Reference
Empirical formula	Ca_2O_4Si	Chemfinder 1999
Molecular weight, g/mol	172.2436	Chemfinder 1999
Density, g/cc	2.97-3.28	Weast et al. 1986
Melting point, °C	NA[a]	NA
Boiling point, °C	NA	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, gL	NA	NA
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.9.3 Toxicity

TLV, mg/m^3: 10 (ACGIH 1998).

D.2.10 Carborundum (Silicon Carbide)
CAS Reg. No. 409-21-2

CSi

D.2.10.1 Background

Used as an abrasive in the M51A1, M508, and M557 fuzes.

D.2.10.2 Physicochemical Properties

Silicon carbide is a solid blue-black material.

TABLE D.6 Silicon Carbide

Properties	Data	Reference
Empirical formula	CSi	Chemfinder 1999
Molecular weight, g/mol	40.097	Chemfinder 1999
Density, g/cc	3.17	Lewis 1991
Melting point, °C	2,600	Lewis 1991
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, gL	NA	NA
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.10.3 Toxicity

Implant TD_{LO} in rats tumorigenic at 200 mg/kg (Sweet 1986).
TLV, mg/m^3: 10 (ACGIH 1998).

D.2.11 DBP (Dibutylphthalate)
CAS Reg. No. 84-74-2

$C_{16}H_{22}0_4$

D.2.11.1 Background

Dibutylphthalate is a minor component of M6 propellant that is used with the M2 and M2A1 4.2-in. cartridge.

D.2.11.2 Physicochemical Properties

Dibutylphthalate is a colorless oily liquid with a very weak aromatic odor.

TABLE D.7 Dibutylphthalate

Properties	Data	Reference
Empirical formula	$C_{16}H_{22}0_4$	Chemfinder 1999
Molecular weight, g/mol	278.3474	Chemfinder 1999
Density, g/mL	1.05	Sax 1984
Melting point, °C	-35	Chemfinder 1999
Boiling point, °C	340	Chemfinder 1999
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility, g/100mL	0.0013	Chemfinder 1999
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.11.3 Toxicity

Oral LD_{50} in rats: 8,000 mg/kg (Sweet 1986).
Oral RfD, mg/kg/d: 0.1 (EPA 1996).
TLV, mg/m^3: 5 (ACGIH 1998).

D.2.12 Dimethylphthalate
CAS Reg. No. 131-11-3

$C_{10}H_{10}O_4$

D.2.12.1 Background

Dimethylphthalate is a component of the M28 propellant, which is an integral part of the M55 rocket.

D.2.12.2 Physicochemical Properties

Dimethylphthalate is a colorless oily liquid with a slight ester odor.

TABLE D.8 Dimethylphthalate

Properties	Data	Reference
Empirical formula	$C_{10}H_{10}O_4$	Chemfinder 1999
Molecular weight, g/mol	194.1866	Chemfinder 1999
Density, g/cc @ 25°C	1.189	Lewis 1991
Melting point, °C	5.5	Fedoroff et al. 1983, Vol. 5, D1367
Boiling point, °C	283.7	Chemfinder 1999
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility, g/100mL	<0.1	Chemfinder 1999
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.12.3 Toxicity

Oral LD_{50} in rats: 6,800 mg/kg (Sweet 1986).
TLV, mg/m^3: 5 (ACGIH 1998).

D.2.13 DNT (2,4-dinitrotoluene)
CAS Reg. No. 121-14-2

$C_7H_6N_2O_4$

D.2.13.1 Background

DNT is a high explosive additive of the M28 propellant, which is an integral part of the M55 rocket. It is also a minor impurity in TNT.

D.2.13.2 Physicochemical Properties

TABLE D.9 2,4-Dinitrotoluene

Properties	Data	Reference
Empirical formula	$C_7H_6N_2O_4$	Chemfinder 1999
Molecular weight, g/mol	182.1354	Chemfinder 1999
Density, g/cc @ 15ºC	1.521	Hartley et al. 1994
Melting point, °C	69	Chemfinder 1999
Boiling point, °C	300 (decomposes)	Sax 1984
Vapor pressure at 25°C, torr	0.000217	Rosenblatt et al. 1991
Aqueous solubility, g/100mL	0.027	Chemfinder 1999
Heat of fusion, cal/g	26.1	Rosenblatt et al. 1991
Heat of vaporization, kcal/mol	22.9	Fedoroff et al. 1983, Vol. 9, T 305
Heat of sublimation, kcal/mol	23.8	Fedoroff et al. 1983, Vol. 9, T 305
Heat of detonation, kcal/kg	1056	Fedoroff et al. 1983, Vol. 9, T 305
Heat of combustion, kcal/mol	853.7	Fedoroff et al. 1983, Vol. 9, T 305

[a] NA = not available.

D.2.13.3 Toxicity

Oral LD_{50} in rats: 268 mg/kg (Sweet 1986); 200–800 (Rosenblatt et al. 1991).
Oral cancer slope factor, $[mg/(kg \times d)]^{-1}$: 0.68 for mixture of 2,4-DNT with 2,6-DNT (SSG); 0.311 (Rosenblatt et al. 1991).
Oral RfD, mg/kg/d: 0.002 (EPA 1996).
TLV (mg/m^3): 0.2 (ACGIH 1998).

D.2.14 DPA (Diphenylamine) CAS Reg. No. 122-39-4

$C_{12}H_{11}N$

D.2.14.1 Background

Diphenylamine is used as a stabilizer in the M6 propellant that is used with the M2 and M2A1 4.2-in. cartridge.

D.2.14.2 Physicochemical Properties

Diphenylamine is a white crystalline solid with a floral odor.

TABLE D.10 Diphenylamine

Properties	Data	Reference
Empirical formula	$C_{12}H_{11}N$	Chemfinder 1999
Molecular weight, g/mol	169.2256	Chemfinder 1999
Density, g/mL	1.16	Sax 1984
Melting point, °C	52	Chemfinder 1999
Boiling point, °C	302	Chemfinder 1999
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility, g/100cc	0.003-0.00357 @25°C	Hartley et al. 1994
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion, cal/g	9.048	Hartley et al. 1994

[a] NA = not available.

D.2.14.3 Toxicity

Oral LD_{50} in guinea pigs: 300 mg/kg (Sweet 1986).
Rat oral LD_{50} range: 1,165–3,200 mg/kg (Hartley et al. 1994).
Oral RfD, mg/kg/d: 2.5×10^{-2} (EPA 1997).
TLV (mg/m^3): 10 (ACGIH 1998).

D.2.15 Ethyl Centralite (N,N'-diethyl-N,N'-diphenylurea) CAS Reg. No. 85-98-3

$C_{17}H_{20}N_2O$

D.2.15.1 Background

Ethyl centralite was developed in Germany for use with double-base propellants. The compound acts as a stabilizer, gelantinizer, and waterproofing agent (U.S. Army 1984). Ethyl centralite is used in the M6 propellant and the M2 igniter, which are components of the 4.2-in. cartridge.

D.2.15.2 Physicochemical Properties

Ethyl centralite is a white crystalline solid.

TABLE D.11 Ethyl Centralite

Properties	Data	Reference
Empirical formula	$C_{17}H_{20}N_2O$	Chemfinder 1999
Molecular weight, g/mol	268.3578	Chemfinder 1999
Density, g/cc @20^{o}C	1.12	Fedoroff et al. 1983, Vol. 2, C 127ff
Melting point, ^{o}C	79	Chemfinder 1999
Boiling point, ^{o}C	325-330	Chemfinder 1999
Vapor pressure at 25^{o}C, torr	NA[a]	NA
Aqueous solubility, g/100cc	0.008 @20^{o}C	Fedoroff et al. 1983, Vol. 2, C 127ff
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion, kcal/g	8,409	Fedoroff et al. 1983, Vol. 2, C 127ff

[a] NA = not available.

D.2.15.3 Toxicity

Intraperitoneal LD_{50} in mice: 200 mg/kg (Sweet 1986).
Rat oral LD_{50}: 2,560 mg/kg (Hartley et al. 1994).

D.2.16 Lead Azide
CAS Reg. No. 13424-46-9

N_6Pb

D.2.16.1 Background

Lead azide was first proposed for use in compound detonators (initiating explosives) by Col. A. A. Solonina of Russia in 1906 (U.S. Army 1984). It is a component of all the fuzes associated with the Assembled Chemical Weapons Assessment (ACWA).

D.2.16.2 Physicochemical Properties

Lead azide is a salt of hydrazoic acid, HN_3. The pure compound has two crystal modifications: an orthorhombic form and a monoclinic form. The orthorhombic form is very sensitive, and production of this crystal form must be avoided during manufacture. The lead azide is treated with various substances (dextrin, polyvinylalcohol, and others) to form six different types of lead azide that are used as detonator material. The data in the table below are for the monoclinic form (U.S. Army 1984).

TABLE D.12 Lead Azide

Properties	Data	Reference
Empirical formula	N_6Pb	U.S. Army 1984
Molecular weight, g/mol	291.2402	Chemfinder 1999
Density, g/cc	4.87	U.S. Army 1984
Melting point, °C	245-250 (decomposes)	U.S. Army
Boiling point, °C		
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility, %	0.02	U.S. Army 1984
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation, kcal/g	0.367	U.S. Army 1984
Heat of combustion	NA	NA
Sensitivity:		
Picatinny Arsenal, in.	2 (2 kg weight)	U.S. Army 1984
Bureau of Mines, cc	30 (2 kg weight)	U.S. Army 1984

[a] NA = not available.

D.2.16.3 Toxicity

TLV (mg/m^3) based on lead content: 0.05 (ACGIH 1998).

D.2.17 Lead Carbonate
CAS Reg. No. 598-63-0

CO_3Pb

D.2.17.1 Background

Lead carbonate is a component of the M1 propellant that is used with the 105-mm cartridge.

D.2.17.2 Physicochemical Properties

TABLE D.13 Lead Carbonate

Properties	Data	Reference
Empirical formula	CO_3Pb	Chemfinder 1999
Molecular weight, g/mol	267.2092	Chemfinder 1999
Density, g/cc	6.6	Fedoroff et al. 1983, Vol. 2, C 127ff
Melting point, °C	315 (with decomposition)	Fedoroff et al. 1983, Vol. 2, C 59
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, g/L	NA	NA
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.17.3 Toxicity

Guinea pig oral TD_{LO}: 1,000 mg/kg (Sweet 1986).
Human oral TD_{LO}: 214 mg/kg (Sweet 1986).
TLV (mg/m^3) based on lead content: 0.05 (ACGIH 1998).

D.2.18 Lead Stearate
CAS Reg. No. 1072-35-1

$C_{36}H_{70}O_4Pb$

D.2.18.1 Background

Lead stearate is a component of the M28 propellant, which is an integral part of the M55 rocket.

D.2.18.2 Physicochemical Properties

TABLE D.14 Lead Stearate

Properties	Data	Reference
Empirical formula	$C_{36}H_{70}O_4Pb$	Chemfinder 1999
Molecular weight, g/mol	774.1466	Chemfinder 1999
Density, g/cc	1.4	Fedoroff et al. 1983, Vol. 9, S 212
Melting point, °C	105-125	Fedoroff et al. 1983, Vol. 9, S 211
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, g/L	NA	NA
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.18.3 Toxicity

Guinea pig oral LD_{LO}: 6,000 mg/kg (Sweet 1986).
TLV (mg/m^3) based on lead content: 0.05 (ACGIH 1998).

D.2.19 Lead Styphnate [1,3-Benzenediol, 2,4,6-trinitro-, lead (2+) salt (1:1)] CAS Reg. No. 15245-44-0 (CAS Reg. Nos: 4219-19-6 and 59286-40-7 may also be applicable)

$C_6HN_3O_8Pb$

D.2.19.1 Background

Lead styphnate is a component of the M417 fuze, which is an integral component of the M55 Rocket.

D.2.19.2 Physicochemical Properties

Two forms of lead styphnate are used as primary explosives: basic and normal (the molecular structure and atomic weight differ). Data in the table below are for normal lead styphnate that is monohydrated. The compound has yellow-orange or reddish-brown, rhombic, needle-like crystals (U.S. Army 1984).

TABLE D.15 Lead Styphnate

Properties	Data	Reference
Empirical formula	$C_6HN_3O_8Pb$	Chemfinder 1999
Molecular weight, g/mol	450.29	Chemfinder 1999
Density, g/cc @ 30°C	3.02	Fedoroff et al. 1983, Vol. 5, D 1278
Melting point, °C	260-310 (explodes)	Fedoroff et al. 1983, Vol. 5, D 1278
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, %	0.04	U.S. Army 1984
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation, cal/g	460	U.S. Army 1984
Heat of combustion, cal/g	1,251	U.S. Army 1984

[a] NA = not available.

D.2.19.3 Toxicity

Rats and mice oral lethal doses: >5,000 mg/kg (Berkowitz et al., 1981).
TLV (mg/m^3) based on lead content: 0.05 (ACGIH 1998).

D.2.20 Lead Thiocyanate
CAS Reg. No. 592-87-0

$C_2N_2PbS_2$

D.2.20.1 Background

Lead thiocyanate is used in the M2 electric squib, which is an integral part of the M55 rocket.

D.2.20.2 Physicochemical Properties

Lead thiocyanate is a white or light-yellow crystalline powder.

TABLE D.16 Lead Thiocyanate

Properties	Data	Reference
Empirical formula	$C_2N_2PbS_2$	Chemfinder 1999
Molecular weight, g/mol	323.3554	Chemfinder 1999
Density, g/cc	3.82	Fedoroff et al. 1983, Vol. 7, L 11
Melting point, °C	NA[a]	NA
Boiling point, °C	NA	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, g/100cc	0.5	Fedoroff et al. 1983, Vol. 7, L 11
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.20.3 Toxicity

TLV (mg/m^3) based on lead content: 0.05 (AGCIH 1998).

D.2.21 Nitrocellulose (cellulose nitrate)
CAS Reg. No. 9004-70-0

$C_6H_7(OH)_x(ONO_2)_y$, where x + y = 3 (representative formula)

D.2.21.1 Background

Nitrocellulose was purified by Sir Frederick A. Abel, an English chemist, in 1865. Abel pulped, washed, and compressed the nitrocellulose in blocks, sheets, discs, and cylinders, which were particularly useful for blasting (U.S. Army 1984). Nitrocellulose is a component of M6 propellant used with the 4.2-in. cartridge and the M28 propellant that is an integral part of the M55 rocket.

D.2.21.2 Physicochemical Properties

Nitrocellulose is a mixture of nitrates obtained by nitrating cellulose. Although there are many sources of cellulose, at the present time it is obtained from coniferous wood. The nitrogen content determines the chemical and physical properties of any particular nitrocellulose. There are five grades of nitrocellulose: pyroxylin or collodion; pyrocellulose; gun cotton; high nitrogen nitrocellulose; and blended nitrocellulose. The high nitrogen nitrocellulose is not used in U.S. standard propellants because it is too costly to manufacture. Nitrocellulose is colorless or slightly yellow (U.S. Army 1984).

TABLE D.17 Nitrocellulose

Properties	Data	Reference
Empirical formula	$C_6H_7(OH)_x(ONO_2)_y$, where $x + y = 3$	U.S. Army1984
Molecular weight, g/mol	NA[a]	NA
Density, g/cc	1.66	Roberts and Hartley 1992
Melting point, °C	160-170	Roberts and Hartley 1992
Boiling point, °C	NA	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, g/L	Insoluble	U.S. Army 1984
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA
Sensitivity:	NA	NA
Picatinny Arsenal, in.	NA	U.S. Army 1984
Bureau of Mines, cc	8	U.S. Army 1984

[a] NA = not available.

D.2.21.3 Toxicity

Nitrocellulose is a water-insoluble fibrous polymer. Consequently, it is not absorbed through the intestinal wall or cell membranes. This accounts for its lack of oral toxicity to mammals (U.S. Army1984). Nontoxic (Roberts and Hartley 1992).

D.2.22 2-Nitrodiphenylamine
CAS Reg. No. 119-75-5

$C_{12}H_{10}N_2O_2$

D.2.22.1 Background

2-Nitrodiphenylamine is a component of M28 propellant, which is an integral part of the M55 rocket.

D.2.22.2 Physicochemical Properties

2-Nitrodiphenylamine is a red-brown crystalline powder.

TABLE D.18 2-Nitrodiphenylamine

Properties	Data	Reference
Empirical formula	$C_{12}H_{10}N_2O_2$	Chemfinder 1999
Molecular weight, g/mol	214.2232	Chemfinder 1999
Density, g/cc	NA[a]	NA
Melting point, °C	75.5	Chemfinder 1999
Boiling point, °C	NA	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility, g/100 mL	1.36	Chemfinder 1999
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion (kcal/mol)	1,488	Fedoroff et al. 1983, Vol. 5, D 1427

[a] NA = not available.

D.2.22.3 Toxicity

No information is available.

D.2.23 Nitroglycerin (1,2,3-propanetriol trinitrate)
CAS Reg. No. 55-63-0

$C_3H_5N_3O_9$

D.2.23.1 Background

Nitroglycerin was invented by Asconio Sobrero, an Italian chemist, in 1846–1847. Because nitroglycerin is very sensitive to slight shocks, commercial use was delayed until the invention of dynamite and blasting gelatin (U.S. Army1984). Nitroglycerin is a major component of M28 propellant, which is used in M55 Rockets.

D.2.23.2 Physicochemical Properties

Nitroglycerin is manufactured by nitrating glycerin in a batch or continuous process. It is a clear, colorless, odorless, oily liquid, and when frozen it forms dipyramidal rhombic crystals. Nitroglycerin is quite stable at temperatures less than 50°C, as shown by storage tests over a period of years (U.S. Army 1984).

TABLE D.19 Nitroglycerin

Properties	Data	Reference
Empirical formula	$C_3H_5N_3O_9$	U.S. Army 1984
Molecular weight, g/mol	227.1	U.S. Army 1984
Density, g/cc	1.596	U.S. Army 1984
Melting point, °C	13.5	U.S. Army 1984
Boiling point, °C	145 (decomposes)	U.S. Army 1984
Vapor pressure at 25°C, torr	0.00177	U.S. Army 1984
Aqueous solubility at 20°C, gL	0.173	U.S. Army 1984
Heat of fusion, cal/g @ 13.5°C	33.2	Fedoroff et al. 1983, Vol. 6, G 98
Heat of vaporization, cal/g	NA[a]	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation, cal/g	1,486	U.S. Army 1984
Heat of combustion cal/g	1603	U.S. Army 1984
Sensitivity:		
Picatinny Arsenal, in.	NA	U.S. Army 1984
Bureau of Mines, cc	16	U.S. Army 1984

[a] NA = not available.

D.2.23.3 Toxicity

Oral LD_{50} in rats: 105 mg/kg (Sweet 1986); 822 mg/kg (male) and 887 mg/kg (female) (Roberts and Hartley 1992).

Oral cancer slope factor, $[mg/(kg \times d)]^{-1}$: 0.0166 (Roberts and Hartley 1992).

TLV (ppm): 0.05 (ACGIH 1998).

D.2.24 Potassium Chlorate
CAS Reg. No. 3811-04-9

$ClK0_3$

D.2.24.1 Background

Potassium chlorate is a component of the M51A1, M508, M557, and M603 fuzes.

D.2.24.2 Physicochemical Properties

Potassium chlorate is a white powder or in the form of transparent colorless crystals (Chemfinder 1999).

TABLE D.20 Potassium Chlorate

Properties	Data	Reference
Empirical formula	$ClK0_3$	Chemfinder 1999
Molecular weight, g/mol	122.5412	Chemfinder 1999
Density, g/cc	2.32	Fedoroff et al. 1983, Vol. 2, C 190
Melting point, ^{o}C	356	Chemfinder 1999
Boiling point, ^{o}C	400	Chemfinder 1999
Vapor pressure at $25^{o}C$, torr	NA[a]	NA
Aqueous solubility g/100 mL	7.10	Chemfinder 1999
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.24.3 Toxicity

Oral LD_{50} in rats: 1,870 mg/kg (Sweet 1986).
Probable oral lethal dose in humans: 50–500 mg/kg (Fedoroff et al. 1983, Vol. 2, C 190).

D.2.25 Potassium Nitrate
CAS Reg. No. 7757-79-1

KNO_3

D.2.25.1 Background

Potassium nitrate is a component of black powder.

D.2.25.2 Physicochemical Properties

Potassium nitrate appears as colorless prisms to white granular or crystalline powder.

TABLE D.21 Potassium Nitrate

Properties	Data	Reference
Empirical formula	KNO_3	Chemfinder 1999
Molecular weight, g/mol	101.0949	Chemfinder 1999
Density, g/cc @ 16°C	2.109	Lewis 1991
Melting point, °C	334	Chemfinder 1999
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility g/100cc	38.34 @ 25°C	Fedoroff et al. 1983, Vol. 8, N-34ff
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.25.3 Toxicity

Oral LD_{50} in rats: 3,750 mg/kg (Sweet 1986).

D.2.26 Potassium Perchlorate
CAS Reg. No. 7778-74-7

$ClKO_4$

D.2.26.1 Background

Potassium perchlorate is used in the M62 igniter, which is an integral component of the M55 rocket.

D.2.26.2 Physicochemical Properties

Potassium perchlorate is a white, hygroscopic powder.

TABLE D.22 Potassium Perchlorate

Properties	Data	Reference
Empirical formula	$ClKO_4$	Chemfinder 1999
Molecular weight, mol/g	138.5406	Chemfinder 1999
Density, g/cc	2.52	Lewis
Melting point, ^oC	588 with decomposition	Fedoroff et al. 1983, Vol. 8, P 164
Boiling point, ^oC	NA[a]	NA
Vapor pressure at 25^oC, torr	NA	NA
Aqueous solubility g/100 mL	0.75 @ 0^oC 12.2 @ 100^oC	Fedoroff et al. 1983, Vol. 8, P 164
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion	NA	NA

[a] NA = not available.

D.2.26.3 Toxicity

No observable adverse effects level (NOAEL), mg/(kg x d): 0.14 (Long 1999).
EPA-proposed oral RfD (as perchlorate), mg/kg/d: 0.0009 (Pontius et al. 1999).

D.2.27 RDX (cyclotrimethylenetrinitramine)
CAS Reg. No. 121-82-4

$C_3H_6N_6O_6$

D.2.27.1 Background

RDX was first prepared by Henning of Germany for medical purposes. E. von Herz of Germany was the first to recognize the value of RDX as an explosive. The first to prepare RDX in quantity was G. C. Hale of Picatinny Arsenal in 1925 (U.S. Army 1984). RDX is a component of Composition B, Composition B4, and Composition A5. It is also a component of the M603 and M417 fuzes used in the M23 land mine and the M55 rocket, respectively.

D.2.27.2 Physicochemical Properties

There are two grades specified for RDX: Type A and Type B. Type A contains no HMX (cyclotetramethylenetetranitramine), and Type B has a constant impurity of from 8 to 12% HMX. The values shown in Table D.23 are for Type A. RDX is a white crystalline solid and is highly stable. In a one-year surveillance test no decomposition occurred at either 65°C or 85°C. In the United States, RDX is stored wetted with water (U.S. Army 1984).

TABLE D.23 RDX

Properties	Data	Reference
Empirical formula	$C_3H_6N_6O_6$	U.S. Army 1984
Molecular weight, g/mol	222.13	U.S. Army 1984
Density, g/cc	1.806	U.S. Army 1984
Melting point, °C	202-203	U.S. Army 1984
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	4.03×10^{-9}	Rosenblatt et al. 1991
Aqueous solubility g/cc	0.006	Rosenblatt et al. 1991
Heat of fusion, cal/g	38.26	Rosenblatt et al. 1991
Heat of vaporization, kcal/mol	26	Fedoroff et al. 1983, Vol 9, R 123
Heat of sublimation, kcal/mol	31.1	Fedoroff et al. 1983, Vol 9, R 123
Heat of detonation, kcal/g	1.62	U.S. Army 1984
Heat of combustion, cal/g	2,307.2	U.S. Army 1984
Sensitivity:		
Picatinny Arsenal, in.	9	U.S. Army 1984
Bureau of Mines, cc	NA	U.S. Army 1984

[a] NA = not available.

D.2.27.3 Toxicity

Oral LD_{50} in rats: 100 mg/kg (Sweet 1986).
TLV, mg/m^3: 0.5 (ACGIH 1998).
Oral RfD, mg/kg/d: 3×10^{-3} (EPA 1997).
Oral cancer slope factor, $[mg/(kg \times d)]^{-2}$: 0.11 (Roberts and Hartley 1992).

D.2.28 Stearic Acid (n-octadecanoate)
CAS Reg. No. 57-11-4

$C_{18}H_{36}0_2$

D.2.28.1 Background

Stearic acid is used as desensitizer in Composition A5.

D.2.28.2 Physicochemical Properties

Stearic acid is a white crystalline fatty acid that is obtained by saponifying tallow or other hard fats containing stearin.

TABLE D.24 Stearic Acid

Properties	Data	Reference
Empirical formula	$C_{18}H_{36}0_2$	Chemfinder 1999
Molecular weight, g/mol	284.4812	Chemfinder 1999
Density, g/mL	0.847	Sax 1984
Melting point, °C	69.3	Chemfinder 1999
Boiling point, °C	361	Chemfinder 1999
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility g/100 mL	0.1-1	Chemfinder 1999
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion, cal/g	-9,616	Sax 1984

[a] NA = not available.

D.2.28.3 Toxicity

Intravenous LD_{50} in rats: 21 mg/kg (Sweet 1986).

D.2.29 Sulfur
CAS Reg. No. 7704-34-9

S_8

D.2.29.1 Background

Sulfur is a component of black powder.

D.2.29.2 Physicochemical Properties

Sulfur appears as yellow crystals as a powder, or as a solid.

TABLE D.25 Sulfur

Properties	Data	Reference
Empirical formula	S_8	Chemfinder 1999
Molecular weight, g/mol	256.48	Chemfinder 1999
Density, g/cc (alpha form)	2.07 @20°C	Fedoroff et al. 1983, Vol. 9, S 242
Melting point, °C	114	Chemfinder 1999
Boiling point, °C	444.6	Chemfinder 1999
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility g/L	NA	NA
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion, cal/g	2,200	Fedoroff et al. 1983, Vol. 9, S 241

[a] NA = not available.

D.2.29.3 Toxicity

Intravenous LD_{50} in rats: 8 mg/kg (Sweet 1986).

D.2.30 Tetracene or Tetrazene (guanyldiazoguanyl tetrazene) CAS Reg. No.

$C_2N_{10}H_8O$

D.2.30.1 Background

Tetracene is a component of the M417 fuze, which is an integral part of the M55 rocket.

D.2.30.2 Physicochemical Properties

Tetracene is a colorless to pale yellow, fluffy material with needle crystals.

TABLE D.26 Tetracene

Properties	Data	Reference
Empirical formula	$C_2H_6N_{10}\cdot H_2O$	U.S. Army 1984
Molecular weight, g/mol	188.15	U.S. Army 1984
Density, g/cc	0.45	U.S. Army 1984
Melting point, °C	129.5	Berkowitz et al. 1981
Boiling point, °C	NA[a]	NA
Vapor pressure at 25°C, torr	NA	NA
Aqueous solubility g/L	Insoluble	U.S. Army 1984
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation, cal/g	658	U.S. Army 1984
Heat of combustion, cal/g	NA	NA
Sensitivity:		
Picatinny Arsenal, in.	8 (226.8-g weight)	U.S. Army 1984
Bureau of Mines, cc	7 (2-kg weight)	U.S. Army 1984

[a] NA = not available.

D.2.30.3 Toxicity

Toxicological testing by the oral route in rats: this has been performed only on "desensitized" tetrazene, with questionable results of 3,350 mg/kg (Berkowitz et al. 1981).

D.2.31 Tetryl (2,4,6-trinitrophenylmethylnitramine) CAS Reg. No. 479-45-8

$C_7H_5N_5O_8$

D.2.31.1 Background

Tetryl is a booster explosive first prepared by Michler and Meyer of Germany in 1879 (U.S Army 1984). It is used for burster material in the 4.2-in. cartridge, as a booster in the M23 land mine, and is combined with TNT to make tetrytol.

As of 1979, the United States has discontinued the use of tetryl. No new components are being designed with tetryl, and all components that contained tetryl are being redesigned to eliminate the tetryl. The reason is the relative instability of tetryl after storage at elevated temperatures (U.S. Army 1984).

D.2.31.2 Physicochemical Properties

Tetryl is a solid crystalline material. The compound is colorless when freshly prepared and highly purified, but rapidly acquires a yellow color when exposed to light. Melting is accompanied by partial decomposition. Tetryl dissolves readily in concentrated nitric acid and moderately well in other mineral acids; however, it is soluble to the extent of only 0.3% in the spent acid after manufacture (U.S. Army 1984).

TABLE D.27 Tetryl

Properties	Data	Reference
Empirical formula	$C_7H_5N_5O_8$	U.S. Army 1984
Molecular weight, g/mol	287.15	U.S. Army 1984
Density, g/cc	1.71	U.S. Army 1984
Melting point, ^oC	129	Chemfinder 1999
Boiling point, ^oC	187 (explodes)	Sax 1984
Vapor pressure at 25^oC, torr	5.69×10^{-9}	Rosenblatt et al. 1991
Aqueous solubility g/100cc	0.008	Rosenblatt et al. 1991
Heat of fusion, kcal/mol	5.9	U.S. Army 1984
Heat of vaporization, kcal/mol	26	U.S. Army 1984
Heat of sublimation, cal/g	NA[a]	NA
Heat of detonation, kcal/g	1.14	Fedoroff et al. 1983, Vol. 7, H 42
Heat of combustion, cal/g	2914	U.S. Army 1984
Sensitivity	More sensitive than TNT	U.S. Army 1984

[a] NA = not available.

D.2.31.3 Toxicity

Subcutaneous LD_{LO} in dogs: 5,000 mg/kg (Sweet 1986).
Subcutaneous LD_{50} in dogs: 500 mg/kg (Roberts and Hartley 1992).
TLV, mg/m^3: 1.5 (ACGIH 1998).

D.2.32 Tetrytol (70/30 mixture of TNT and tetryl)

D.2.32.1 Background

Tetrytols are light yellow to buff mixtures of TNT and tetryl. Tetrytols resemble tetryl more closely than they resemble TNT. As is the case for tetryl, tetrytols are no longer used by the United States but are still being used by other nations, including various North Atlantic Treaty Organization (NATO) allies (U.S. Army 1984). Tetrytol was used a burster material for the 105-mm and 155-mm projectiles and in the M55 rocket.

D.2.32.2 Physicochemical Properties

Tetrytol is manufactured by heating TNT in a melting kettle equipped with an agitator until the temperature of the liquid exceeds 100^{o}C. The proper amount of tetryl is then added. The temperature is allowed to decrease until the mixture has thickened suitable for pouring in the melt loading operation. TNT and tetryl form a eutectic mixture that has a freezing point of 67.5 C. The solubility characteristics and chemical reactivity of the tetrytol are essentially those of the individual components. Tetrytol is less sensitive than tetryl and more sensitive than TNT (U.S. Army 1984).

D.2.32.3 Toxicity

See TNT and tetryl.

D.2.33 Triacetin (Glycerol Triacetate)
CAS Reg. No. 102-76-1

$C_9H_{14}O_6$

D.2.33.1 Background

Triacetin is a component of the M28 propellant, which is an integral part of the M55 rocket.

D.2.33.2 Physicochemical Properties

Triacetin is a colorless liquid.

TABLE D.28 Triacetin

Properties	Data	Reference
Empirical formula	$C_9H_{14}O_6$	Chemfinder 1999
Molecular weight, g/mol	218.206	Chemfinder 1999
Density, g/cc @ 20°C	1,163	Fedoroff et al. 1983, Vol 1, A31 ff
Melting point, °C	-78	Lewis 1991
Boiling point, °C	258	Chemfinder 1999
Vapor pressure at 25°C, torr	NA[a]	NA
Aqueous solubility g/L	NA	NA
Heat of fusion, cal/g	NA	NA
Heat of vaporization, cal/g	NA	NA
Heat of sublimation, cal/g	NA	NA
Heat of detonation	NA	NA
Heat of combustion, kcal/mol	1,008.6	Fedoroff et al. 1983, Vol 1, A32

[a] NA = not available.

D.2.33.3 Toxicity

Oral LD_{50} in rats: 3,000 mg/kg (Sweet 1986).

D.2.34 TNT (2,4,6-trinitrotoluene)
CAS Reg. No. 118-96-7

$C_7H_5N_3O_6$

D.2.34.1 Background

TNT was first prepared by J. Willibrand, a German scientist, in 1863. Although TNT was used for many years in the dye industry, it was not used as an explosive until 1904. Thereafter, TNT became one of the most commonly used high explosives (U.S. Army 1984). It is used as a burster in the 155-mm and 8-in. projectiles and as a component of tetrytol, Composition B, and Composition B4.

D.2.34.2 Physicochemical Properties

The properties of TNT make it the most highly used explosive since World War I to the present. Such properties include safety in handling, fairly high explosive power, good chemical and thermal stability, favorable physical properties, compatibility with other explosives, and a low melting point favorable for melt casting operations. TNT is a yellow crystalline compound, and it does not undergo decomposition when melted (U.S. Army 1984).

TABLE D.29 TNT

Properties	Data	Reference
Empirical formula	$C_7H_5N_3O_6$	U.S. Army 1984
Molecular weight, g/mol	227.13	U.S. Army 1984
Density, g/cc	1.654	U.S. Army 1984
Melting point, °C	80-81	U.S. Army 1984
Boiling point, °C	345	U.S. Army 1984
Vapor pressure at 25°C, torr	5.51×10^{-6}	Rosenblatt et al. 1991
Aqueous solubility g/100cc	0.015 @ 25°C	Rosenblatt et al. 1991
Heat of fusion, cal/g	23.53	U.S. Army 1984
Heat of vaporization, kcal/mol	17-22.7	U.S. Army 1984
Heat of sublimation, kcal/mol	23.2-33.7	U.S. Army 1984
Heat of detonation, kcal/gm	1.41	U.S. Army 1984
Heat of combustion, cal/gol	3,563-3,598	U.S. Army 1984
Sensitivity:		
Picatinny Arsenal, in.	14 (2-kg weight)	U.S. Army1984
Bureau of Mines, cc	NA[a]	U.S. Army1984

[a] NA = not available.

D.2.34.3 Toxicity

Oral LD_{50} in rats: 795 mg/kg (Sweet 1986).
Oral LD_{50} in rats (range); 800–1300 mg/kg (Rosenblatt et al. 1991)
Oral RfD, mg/kg/d: 5×10^{-4} (EPA 1997).
Oral cancer slope factor, $[mg/(kg \times d)]^{-1}$: 0.03 (Roberts and Hartley 1992).
TLV, mg/m^3: 0.1 (ACGIH 1998).

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APPENDIX E:

PROCESS FOR BASELINE INCINERATION OF ASSEMBLED CHEMICAL WEAPONS

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FOREWORD

This document provides a very basic description of the baseline incineration technology currently used at the U.S. Army's Tooele Chemical Agent Disposal Facility (TOCDF).

Four Assembled Chemical Weapons Assessment (ACWA) technology systems are presently under consideration for pilot-scale testing. These systems and their corresponding processes are as follows:

- Primary destruction: agent and energetics neutralization; secondary destruction: supercritical water oxidation (SCWO) (demonstrated by General Atomics).
- Primary destruction: agent and energetics neutralization, secondary destruction: biological treatment (demonstrated by Parsons/Honeywell*).
- Primary destruction: agent and energetics neutralization, gas-phase chemical reduction (GPCR), and transpiring-wall supercritical water oxidation (TW-SCWO) (demonstrated by Foster Wheeler/ Eco Logic/Kvaerner). This system is referred to as neutralization/ GPCR/TW-SCWO.
- Primary destruction: electrochemical oxidation via the SILVER II process (AEA/CH2M Hill). The technology provider indicates that no secondary treatment is needed. This system is referred to as electrochemical oxidation.

While baseline incineration is not an ACWA technology system, each of the ACWA systems borrows one or more components of the baseline incineration process (e.g., reverse assembly, pollution abatement system). Thus, review of the baseline incineration process is important in gaining a complete understanding of the ACWA systems.

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* Honeywell purchased AlliedSignal in early 2000; General Electric purchased Honeywell in 2000.

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CONTENTS

TABLE

FIGURES

FIGURES (Cont.)

NOTATION

The following is a list of the acronyms, initialisms, and abbreviations used in this appendix.

ACW	assembled chemical weapons
ACWA	Assembled Chemical Weapons Assessment
ANAD	Anniston Army Depot
BRS	burster removal station
BSRM	burster size reduction machine
CDF	chemical demilitarization facility
CHB	Container Handling Building
CMDA	Chemical Materials Destruction Agency
COE	U.S. Army Corps of Engineers
DCD	Deseret Chemical Depot
DFS	deactivation furnace system
DPE	demilitarization protective ensemble
DUN	dunnage incinerator
ECR	explosion-containment room
ECV	explosion-containment vestibule
EPA	U.S. Environmental Protection Agency
HDC	heated discharge conveyor
HEPA	high-efficiency particulate air
JACADS	Johnston Atoll Chemical Agent Disposal System
LIC	liquid incinerator
MDM	multipurpose demilitarization machine
MITRE	MITRE Corporation
MPF	metal parts furnace
MPRS	miscellaneous parts removal station
NRC	National Research Council
ONC	on-site container
PAS	pollution abatement system
PBA	Pine Bluff Arsenal
PIC	product of incomplete combustion
PMACWA	U.S. Department of Defense, Program Manager for Assembled Chemical Weapons
PMCD	U.S. Army, Program Manager for Chemical Demilitarization
PMD	projectile/mortar disassembly
RSM	rocket shear machine
SAIC	Science Applications International Corporation
TOCDF	Tooele Chemical Agent Disposal Facility
TOX	toxic cubicle
TRD	technical resource document
UMDA	Umatilla Depot Activity
UPA	unpack area

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APPENDIX E:

BASELINE INCINERATION OF ASSEMBLED CHEMICAL WEAPONS

E.1 INTRODUCTION

This appendix to the Technical Resource Document (TRD) provides a very basic description of the baseline incineration technology currently in use at the U.S. Army Tooele Chemical Agent Disposal Facility (TOCDF). While baseline incineration is not a technology being considered under the Assembled Chemical Weapons Assessment (ACWA) program, each of the ACWA systems borrows one or more components of the baseline incineration process (e.g., reverse assembly, pollution abatement system). Thus, review of the baseline incineration process is important in gaining a complete understanding of the ACWA systems

The baseline approach to destruction of the nation's stockpile of assembled chemical weapons (ACW) is referred to as baseline incineration. Table E.1 provides an overview of the baseline incineration process. For comparative purposes, the table also shows candidate ACWA technologies. Munitions access is accomplished by using baseline reverse assembly. Destruction of the agent drained from munitions and liquid secondary waste is accomplished by the liquid incinerator (LIC). The deactivation furnace system (DFS) is used to treat energetics and rocket components. Projectile and mortar bodies are treated to a 5X condition with the baseline metal parts furnace (MPF), and dunnage is treated by thermal treatment in the Dunnage Incinerator (DUN).[1] A more detailed description of the baseline incineration system follows.

E.2 PAST USE OF BASELINE INCINERATION

The U.S. Department of Defense (DOD) previously defined baseline incineration as the technology and process design that was used at the Johnston Atoll Chemical Agent Disposal System (JACADS), located on Johnston Island in the Pacific Ocean (PMCD 1988). ACW destruction at JACADS has been completed. Baseline incineration is currently being used at the TOCDF, located at Deseret Chemical Depot (DCD) in Utah. Operating experience has resulted in improvements to the baseline incineration processes currently in place at TOCDF. Incinerators are currently being constructed at Pine Bluff Arsenal (PBA), Umatilla Depot Activity (UMDA), and Anniston Army Depot (ANAD). The information presented in this document is based in part on the Army's original process description (PMCD 1988).

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[1] Because the DUN incinerator has had some design problems, dunnage at TOCDF is currently being stored pending a final solution.

TABLE E.1 Technology Overview for Baseline Incineration and Proposed ACWA Technology Systems[a]

Technology	Munitions Access	Agent Treatment	Energetics Treatment	Metal Parts Treatment	Dunnage Treatment
Baseline incineration	Baseline reverse assembly	Liquid incinerator (LIC) (a stationary LIC)	Deactivation Furnace System (DFS) (a rotary kiln incinerator), with heated discharge conveyor (HDC)	Metal Parts Furnace (MPF) (a roller hearth incinerator)	Size reduction and stationary bed incinerator
Neutralization/ SCWO	Parts of baseline reverse assembly, cryofracture	Hydrolysis[b] followed by SCWO	Caustic hydrolysis followed by SCWO	Caustic hydrolysis followed by thermal treatment with steam	Size reduction and pulping followed by SCWO
Neutralization/ biotreatment[c]	Modified baseline reverse assembly (fluid-abrasive cutting and fluid-mining)	Hydrolysis[b] followed by biotreatment	Caustic hydrolysis followed by biotreatment	Thermal treatment with steam	Size reduction/thermal treatment with steam
Neutralization/ GPCR/TW-SCWO	Modified baseline reverse assembly (uses baseline process with modified equipment)	Hydrolysis[b] followed by TW-SCWO	Caustic hydrolysis followed by TW-SCWO	Caustic hydrolysis and spray washing followed by GPCR using hydrogen and steam	GPCR using hydrogen and steam
Electrochemical-oxidation	Modified baseline reverse assembly (fluid-abrasive cutting and fluid-mining)	Electrochemical oxidation using SILVER II process	Electrochemical oxidation using SILVER II process	Detonation chamber and thermal treatment with steam	Size reduction followed by thermal treatment with steam

[a] Combinations of these technologies may also be considered.

[b] Nerve agents are treated using caustic hydrolysis; mustard agents are treated using water hydrolysis followed by a caustic wash.

[c] Biotreatment is viable for mustard agents only.

Source: Adapted from PMACWA (1999a; 2001a,b).

Incineration is a proven technology currently in wide use in private industry as a means of destroying organic compounds in hazardous waste. The U.S. Environmental Protection Agency's (EPA's) land disposal restrictions program for treatment of organic constituents in hazardous waste is based primarily on incineration (Title 40, Part 268 of the *Code of Federal Regulations* [40 CFR Part 268]).

E.3 BASELINE INCINERATION 1988 PROCESS DESCRIPTION

Figure E.1 is a schematic diagram of the overall baseline incineration process. Energetics are separated from the munition item in an explosive-containment structure, while agent accessing requires only vapor containment. The component agent and energetics are then incinerated, metal parts are decontaminated to a 5X condition, and dunnage is incinerated. Pollution abatement systems, consisting of cooling towers, caustic scrubbers, high-efficiency particulate air (HEPA) filters, and carbon filters are used to control emissions to the atmosphere. The primary waste materials that are generated by incineration consist of scrubber brine salts and incinerator residue (ash and slag). The component processes are described below.

E.3.1 MUNITIONS ACCESS

The baseline munitions access process differs slightly for each of the major types of ACW: projectiles and mortars, M55 rockets (and M56 rocket warheads), and land mines. In addition, the access process for overpacked munitions and munitions that leak during transport varies. The processes for each of these ACW types are described below. Much of each description has been summarized from information provided in Appendix C of NRC (1999).

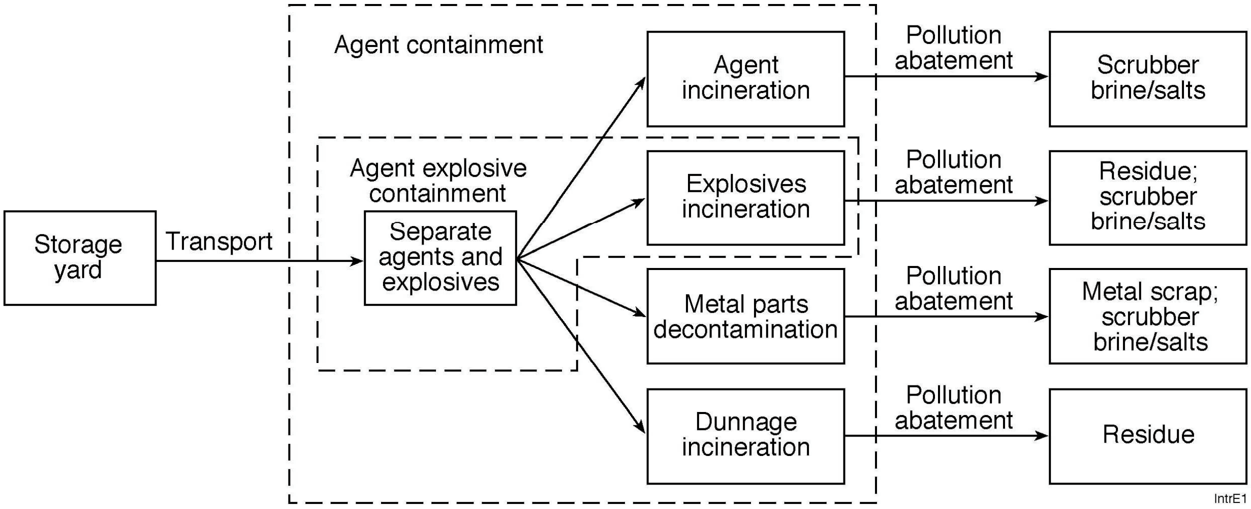

FIGURE E.1 Baseline Incineration Process (Source: CMDA 1993)

E.3.1.1 Projectiles and Mortars

The demilitarization process begins with removal of pallets containing stored projectiles and mortars from the storage igloo. The pallet is removed from storage using a forklift and placed into a cylindrical steel vessel known as an on-site container (ONC). The ONC is brought to the Container Handling Building (CHB) via truck. The ONC is sealed during transport to the unpack area (UPA) of the chemical demilitarization facility (CDF) to prevent releases to the inside of the truck or the environment in the event of leakage. The CHB buffers the ONCs prior to transport to the UPA. Once inside the UPA, the ONC is sampled to determine whether a leak has developed during transport. If no leak is detected, the ONC is opened and the pallet is removed. The projectiles and mortars are manually removed from the pallet and other packing materials and placed base first, one at a time, on a conveyor. From here on, operations are conducted remotely via mechanized systems.

The conveyor moves the item through an airlock to the explosion-containment vestibule (ECV), and then to the explosion-containment room (ECR), where explosives are removed. The ECR and ECV are separated from the rest of the facility by blast gates, which are designed to contain an explosion should the item detonate during processing.

Figure E.2 illustrates disassembly of projectiles and mortars using the baseline process. Once inside the ECR, the item is conveyed to the projectile/mortar disassembly (PMD) machine. This machine removes the energetic components from the item in three steps. At the nose-closure removal station (NCRS), a hydraulic chuck unscrews the assembly (fuze and booster, or lifting plug) from the shell. Then, at the miscellaneous parts removal station (MPRS), the fuze well cups, supplementary charges, and other hardware are removed. Finally, at the burster removal station (BRS), high-pressure air is used to remove the burster. A burster size-reduction machine (BSRM) then shears the burster into pieces. The fuze, booster, and sheared burster are subsequently fed to the DFS.

The munition body, with its energetic components removed, then exits the ECR and is conveyed by the multipurpose loader to the munitions processing bay. Here, pick-and-place robots load the munition bodies into the multipurpose demilitarization machine (MDM). The burster well is extracted at the pull and drain station of the MDM.[2] Once the burster well has been removed, a drain tube is inserted into the agent reservoir, and liquid agent is vacuumed into an agent collection system, quantified, and then pumped through a strainer to an agent holding tank. The agent holding tank is located in the toxic cubical (TOX). A minimum of 95% of the liquid agent is removed from the projectile or mortar in this manner (design requirement). Following the drain operation, the burster well is crimped to prevent reseating and is placed back into the munition body. These munitions bodies are then conveyed to a metal parts furnace (MPF) for thermal treatment to a 5X condition. Dunnage, including all packing materials, proceeds to the DUN. Because the DUN has had some design problems, shredded dunnage at TOCDF is currently being stored, pending a final solution.

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[2] Some bursters are welded into place. The MDM has a bore station that is used for milling-out the weld.

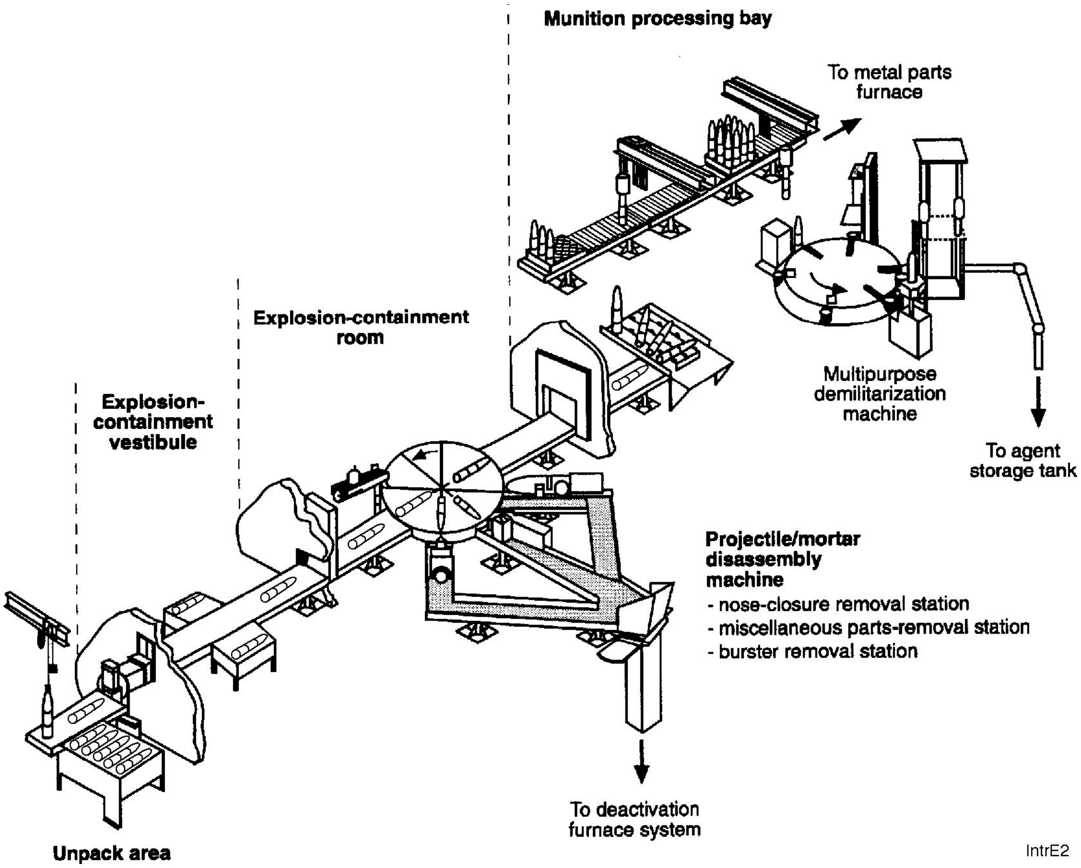

FIGURE E.2 Baseline Disassembly of Projectiles and Mortars (Source: Adapted from COE 1987)

E.3.1.2 M55 Rockets and M56 Rocket Warheads

Figure E.3 portrays the baseline disassembly process for rockets. The rockets and warheads are conveyed to the CDF in essentially the same manner as are projectiles and mortars. Once inside the ECR, the rockets and warheads, still within their fiberglass shipping/firing tubes, are removed from the pallet and conveyed to the punch and drain station of the rocket-shear machine (RSM). At the RSM, holes are punched through the exterior of the tubes and into the rocket warheads. The agent is then vacuum-drained and pumped to an agent storage tank in the TOX. As with projectiles and mortars, design requirements call for a minimum of 95% of the agent to be drained from the rocket. The drained rockets then move via conveyor to the shear station of the RSM, where a hydraulic guillotine-type device shears the rocket into eight segments. The first cut separates the fuze from the rocket, while the remaining cuts segment the burster and propellant. The rocket pieces drop into a hopper and are fed into the DFS. To avoid detonation of the burster or propellant, the fuze is fed separately into the furnace. Treatment of dunnage and metal parts associated with the rockets is identical to that employed for projectiles and mortars.

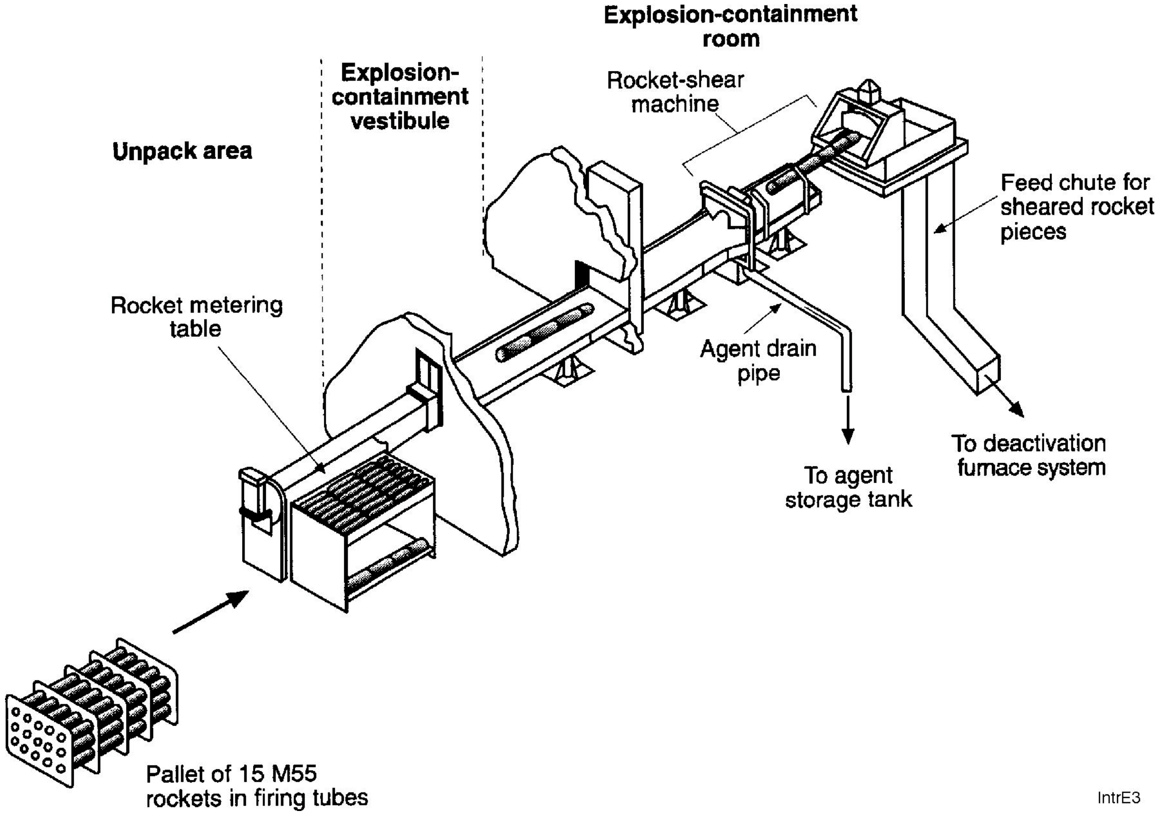

FIGURE E.3 Baseline Disassembly of M55 Rockets and M56 Rocket Warheads (Source: Adapted from COE 1987)

E.3.1.3 M23 Land Mines

The baseline disassembly process for the M23 land mines is depicted in Figure E.4. The land mines are conveyed to the CDF in essentially the same manner as are rockets and projectiles and mortars. The mines are contained in drums (three mines to a drum) with detached fuzes and activators. Once the land mines have been received at the CDF, the first step is removal of the mines from the pallet. Individual drums are conveyed using a forklift and mechanical lift to a mine glove box. The glove box is an air-tight enclosed area that is located in the UPA that feeds to the ECV. The drums are manually unpacked inside the glove box. Fuzes and activators are removed from the drums, and arming plugs are removed from the mines. The fuzes, activators, and arming plugs are then placed in a fuze box that is identical in size and shape to the mine casing. The fuze boxes and the mine casing are then placed sequentially on a conveyor leading to the ECV, and eventually the ECR. The fuze boxes are fed directly to the DFS. Disassembly of the mine continues in the ECR by using the mine machine. Here, the mine is punched through its side, and the agent is vacuum-drained and pumped to a holding tank in the TOX. Here again, design requirements call for a minimum of 95% of the agent to be drained from the mine. Following draining, the central booster is removed at the booster push-out station. The booster and the mine body are then fed separately to the DFS. Treatment of dunnage and metal parts associated with the land mines is identical to that employed for projectiles and mortars.

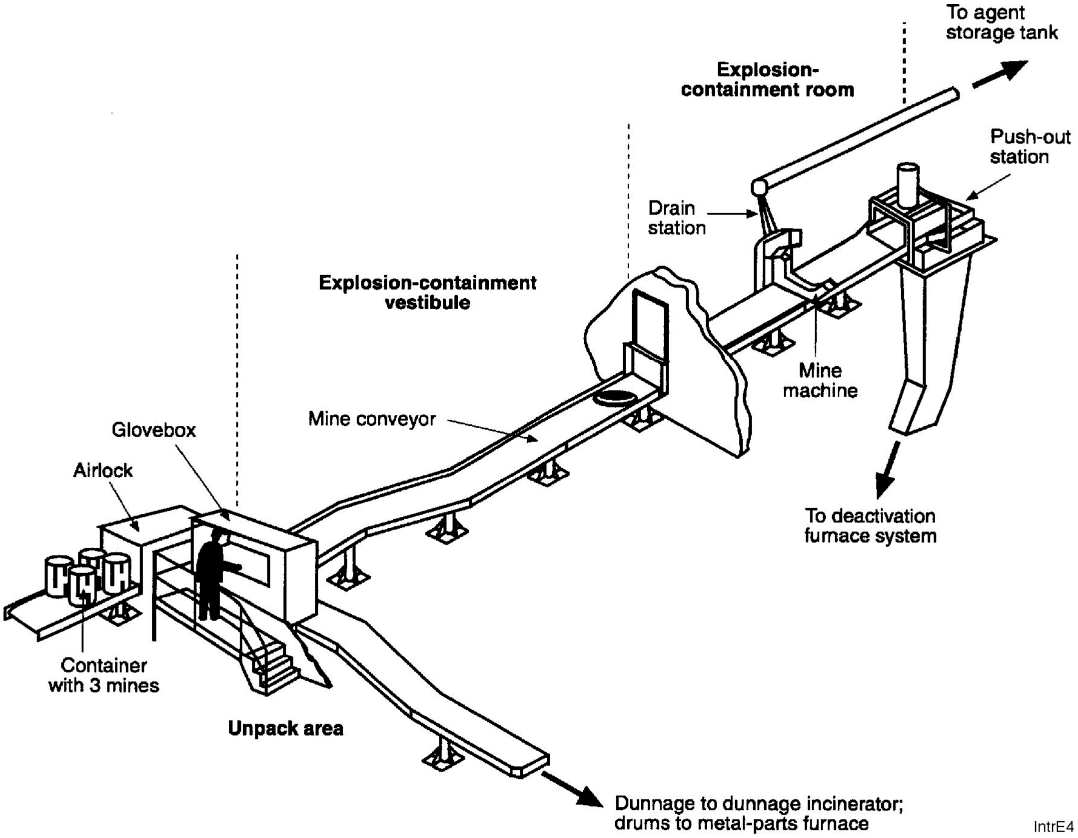

FIGURE E.4 Baseline Disassembly of M23 Land Mines (Source: Adapted from COE 1987)

E.3.1.4 Munitions That Leak during Transport

If a leak is detected inside the ONC at the UPA, the ONC is trucked to the toxic maintenance area, where the ONC is opened by operators in demilitarization protective ensemble (DPE) suits. From there, the pallet is removed from the ONC, and the pallet, the ONC, and the exterior of the munition are decontaminated using decontamination solution (e.g., sodium hydroxide solution, bleach). The pallet is then placed on a tray and conveyed backwards through the CDF via conveyor to the ECV. In the ECV, the leaking munition is manually unpacked and conveyed to the ECR, where disassembly takes place. Disassembly is identical to that for nonleaking munitions (NRC 1999).

E.3.1.5 Overpacked Leakers

For overpacked leakers, the procedure for removal from the storage igloo and transport to the CDF is identical to that described for nonleakers. Once leakers reach the CDF, the pallet of overpacked leakers is manually placed on a conveyor and passed through an air-lock to the ECV.

There, operators in DPE suits manually remove the items from the overpack containers and load them onto the conveyor, where they are transported into the ECR. From there, disassembly is identical to that for nonleaking munitions (NRC 1999).

E.3.2 AGENT TREATMENT

Once agent is drained from the munition item, it is temporarily stored in the TOX until transferred to the LIC. The LIC is a stationary liquid-injection incinerator that is also used to incinerate spent decontamination fluids (e.g., those used to decontaminate leakers, DPE suits, etc.). The LIC includes a secondary combustion chamber to minimize the formation of products of incomplete combustion (PICs). Spent decontamination fluids are also fed to the LIC.

E.3.3 ENERGETICS TREATMENT

Energetics are treated in a deactivation furnace system (DFS). The DFS consists of an explosive-hardened rotary kiln furnace and is followed by the heated discharge conveyor (HDC). The kiln is heated by direct, fuel-fired combustion, and the HDC is an electric tunnel furnace. Like the LIC, the DFS includes a secondary combustion chamber to minimize the formation of PICs.

E.3.4 METAL PARTS TREATMENT

Metal parts, which may contain residual agent and/or energetics, are thermally treated in the MPF, a roller hearth incinerator. Like the LIC, the MPF includes a secondary combustion chamber to minimize the formation of PICs.

E.3.5 DUNNAGE TREATMENT

Combustible dunnage is incinerated in the DUN. While dunnage may be contaminated with agent, it is unlikely that dunnage will be contaminated with energetics. Like the LIC, the DUN includes a secondary combustion chamber to minimize the formation of PICs. As indicated previously, the DUN has had some design problems. Dunnage at JACADS and TOCDF is currently being stored, pending a final solution.

E.3.6 EFFLUENT MANAGEMENT AND POLLUTION CONTROLS

As indicated previously, all four incinerators used in the baseline process have secondary combustion chambers to minimize the formation of PICs. A pollution abatement system (PAS) is installed for each incinerator and for the brine reduction area, where liquid effluents from the PAS from each incinerator are evaporated to dryness (less than 10% water content). The PAS consists primarily of a quench tower to lower the gas temperature, and condensers and scrubbers.

E.4 IMPROVEMENTS TO THE 1988 BASELINE INCINERATION PROCESS

On the basis of experience with application of baseline incineration at JACADS and TOCDF, the following improvements were made:

- At JACADS, an M55 rocket burster initiated in 1994 during the shearing process (SAIC 1996, as cited in NRC 1999). The containment system functioned as designed, but the disassembly machinery incurred considerable damage. The technology was subsequently modified to include additional water sprays to irrigate the cutting zone during shearing operations (NRC 1999).

- MDM used to pull the burster wells and drain agent from mortars and projectiles were found to be somewhat unreliable during operational verification testing at JACADS. Entry by personnel in DPE suits was often required (MITRE 1993). Subsequent modifications in system design have been made to improve performance (NRC 1999).

- Difficulties with unscrewing nose closures on projectiles and mortars prompted minor modifications to the disassembly equipment. Specifically, the equipment was modified to be able to deal with the different pitch on the nose closure threads. Still, the U.S. Army Program Manager for Demilitarization (PMCD) reported that between 5.1 and 8.6% of all projectiles (depending on the type of projectile) are rejected because of some failure in the disassembly process (NRC 1999). These items are processed manually.

- Sometimes, agent in mustard mortar rounds can be so thick that the agent cannot be drained as designed. In lieu of draining, these rounds are fed to the MPF at a reduced rate. The agent volatilizes from the inside of the mortar shell and is thermally treated.

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