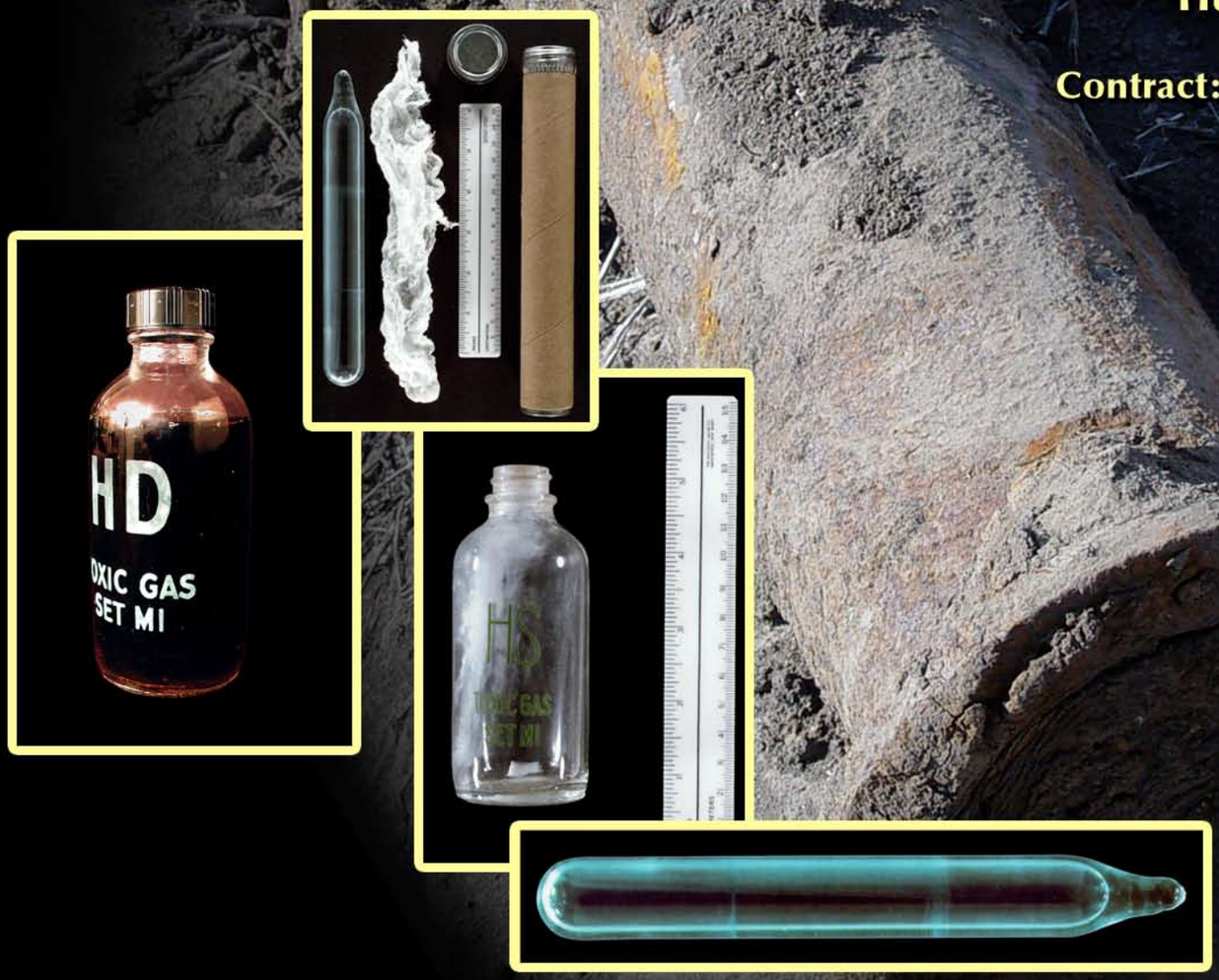
Final Programmatic Remedial Investigation and Feasibility Study For Possible CAIS Sites

CWM Scoping and Security Study

submitted to:
U.S. Army Engineering and Support Center
Huntsville, Alabama

Contract: DACA87-00-D-0038
Delivery Order: 27



submitted by:
PARSONS
September 2007

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Prepared For:

U.S. ARMY ENGINEERING AND SUPPORT CENTER, HUNTSVILLE

Contract DACA87-00-D-0038
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LIST OF ACRONYMS AND ABBREVIATIONS

AAF	Army Airfield
ABP	Agent Breakdown Products
ACGIH	American Conference of Industrial Hygienists
ARAR	Applicable or Relevant and Appropriate
ASR	Archives Search Report
BIP	Blown In Place
BRAC	Base Realignment and Closure
C	Celsius degrees
CAIS	Chemical Agent Identification Set
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CG	Phosgene
CK	Cyanogen Chloride
CMS	Corrective Measures Study
CMI	Corrective Measures Implementation
CN	Chloroacetophenone
CSS	Chemical Safety Submission
CVAA	2-Chlorovinyl Arsenious Acid
CVAO	2-Chlorovinylarsine Oxide
CWM	Chemical Warfare Materiel
CWS	Chemical Warfare Service
DAAMS	Depot Area Air Monitoring System
DANC	Decontamination Agent Non-Corrosive
DEA	Diethanolamine
DGM	Digital Geophysical Mapping
DM	Adamsite
DoD	Department of Defense
DS2	Decontaminating Solution 2
ECBC	Edgewood Chemical Biological Center
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
FUDS	Formerly Used Defense Site
GA	Tabun
GA-sim	Tabun simulant (diethyl malonate)
GPL	General Population Limit

GPR	Ground Penetrating Radar
H	Mustard
HCl	Hydrochloric Acid
HD	Mustard (distilled)
HN-1	Nitrogen mustard
HN-3	Nitrogen mustard
HS	Mustard
HSDB	Hazardous Substances Database
HTW	Hazardous and Toxic Waste
ICt_{50}	Median Incapacitating Dosage
IDW	Investigation-Derived Waste
INPR	Inventory Project Report
L	Lewisite
LBGR	Lowry Bombing and Gunnery Range
LCt_{50}	Median Lethal Dosage (vapor or aerosol)
LD_{50}	Lethal Dosage (non-inhalation)
LUC	Land Use Control
M-1	Lewisite
MEC	Munitions and Explosives of Concern
MINICAMS	Miniature Chemical Agent Monitoring System
NDAI	No DoD Action Indicated
OSHA	Occupational Safety and Health Administration
PA	Preliminary Assessment
PEL	Permissible Exposure Limit (OSHA)
PCD	Pueblo Chemical Depot
PIP	Public Involvement Plan
PS	Chloropicrin
QA	Quality Assurance
RA	Remedial Action
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RFA	RCRA Facility Assessment
RI	Remedial Investigation
SI	Site Inspection
STB	Super Tropical Bleach
STEL	Short-Term Exposure Limit

TBC	To Be Considered
TDG	Thiodiglycol
TEA	Triethanolamine
TE	U.S. Army 22^{d} Chemical Battalion (TE)
TEU	Technical Escort Unit
TLV	Threshold Limit Value (ACGIH)
TR	Target Range
U.S. EPA	United States Environmental Protection Agency
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAESCH	U.S. Army Engineering and Support Center, Huntsville
WPL	Worker Population Limit

EXECUTIVE SUMMARY

ES.1. This Programmatic Remedial Investigation and Feasibility Study (RI/FS) will be used to support decisions for Chemical Warfare Materiel (CWM) sites where chemical agent identification sets (CAIS) may remain. Although developed in the form of an RI/FS for Formerly Used Defense Sites consistent with the Comprehensive Environmental Response, Conservation and Liability Act, the RI/FS will be directly applicable to similar sites with active facilities or facilities undergoing Base Realignment and Closure. It is assumed that the site-specific information will be used in combination with this document to recommend a remedy for CAIS. CAIS were expendable training aids used by the U.S. military for training personnel in the identification and decontamination of the chemical agents and industrial chemicals used in chemical warfare. CAIS consist of small glass containers filled with chemical agent and industrial chemical samples. More than 100,000 CAIS were produced from 1928 to 1969.

ES.2. This Programmatic RI/FS is applicable for a site if all of the following criteria are met:

1. The site has been categorized as a suspect CWM site.
2. CAIS are the only potential CWM suspected to remain at the site.
3. No specific CAIS burial locations are known or suspected for the site.
4. A removal action has been completed for known CAIS burial locations.
5. CAIS have not already been addressed in previous studies that have resulted in an agreement with regulators as to what action should be taken.

ES.3. The CWM Scoping and Security Study identified a group of suspect CWM sites where CAIS were either stored or used for chemical warfare training. Historical records reviewed for these sites indicated that CAIS was the only potential CWM that may remain at the site. Since historical records are incomplete and typically do not include information on the final disposition of the CAIS at these sites, there is a remote chance that buried CAIS may remain in portions of the property. Further investigation of these sites is considered technically unfeasible due to the limitations of available exploratory technology. CAIS were normally packaged in cardboard (sometimes with metal lids and bottoms) and stored in small steel cans, steel shipping containers (pigs), wooden boxes, or plastic cases. The steel drums and pigs represent good metallic targets readily detected by geophysical equipment; however, the wooden boxes, plastic cases, and loose bottles and ampoules contain little or no metal and are not detected by current geophysical technology.

ES.4. Case histories are presented to document the instances where CAIS were recovered at various military installations. These case histories include how CAIS have been accidentally encountered and how investigations were conducted to find and attempt to remove CAIS hazards.

ES.5. Analyses of soils collected from directly beneath CAIS ampoules and bottles found in investigations have been non-detect or at very low levels for chemical agent and agent breakdown products. Similarly, groundwater and surface water samples at the study sites have not provided detections. One exception, at Raritan Arsenal, where hundreds of CAIS were buried in pits and many were found broken, mustard was detected at low levels in groundwater. Because of the small quantities of chemical agents and industrial chemicals in the CAIS, analysis of environmental samples has not been productive as a means of investigation.

ES.6. For suspect CAIS sites, the nature and extent of contamination from CAIS chemicals is unknown. Based on general information and incomplete records, estimates of the typical locations where training was conducted and the approximate numbers of CAIS used in training can be made; however, disposal locations can be outside of the known or suspected training locations at a given facility. Many facilities had small numbers of CAIS on hand toward the end of World War II but these remaining CAIS may have been used in training, retrieved and returned to a major storage point, destroyed onsite, or another accepted practice was burial, as a last resort. Also, records are not available for most types of CAIS and for time periods other than World War II.

ES.7. Ampoules or bottles from CAIS could have been disposed of at or near the CWM training areas or various locations within the former facility boundaries. These containers could consist of unopened intact; crushed; partially-filled; or empty ampoules or bottles. CAIS chemicals may also exist in the soil from use during chemical warfare training. The potential routes of contamination migration include air, soil, surface water, ground water, and through biota. Based on these potential exposure pathways, remedial action objectives (protecting human health and the environment) can be achieved by reducing contact with chemical agent or chemical agent-impacted media (including dermal contact, ingestion, and inhalation) from CAIS.

ES.8. Based on the evaluation of CAIS and the conditions under which they might remain at a site, five alternatives, including No DoD Action Indicated alternative, were developed for consideration. The five alternatives are:

1. No DoD Action Indicated.
2. Access controls.
3. Education awareness and training.
4. Geophysics and intrusive investigation.
5. Excavation and restoration.

ES.9. Five response action alternatives were evaluated against the screening criteria of (i) overall protection of human health and the environment; (ii) compliance with applicable or relevant and appropriate requirements; (iii) long-term effectiveness and permanence; (iv) reduction of toxicity, mobility, or volume; (v) short-term effectiveness; (vi) implementability; and (vii) cost. Although not all of the identified alternatives met all of the screening criteria, all five of the response action alternatives were retained for detailed analysis.

ES.10. The remedial action alternatives are compared and evaluated with respect to seven evaluation criteria developed to address the statutory requirements and preferences of CERCLA. A recommended alternative was selected based on:

- Evaluation of seven CERCLA criteria;
- Consideration of the toxicity, fate, and persistence of CAIS chemicals;
- Evaluation of exposure pathways; and
- Information from previous investigations and accidental encounters with buried CAIS.

ES. 11. The recommended alternative for all sites categorized as suspect CWM sites that have CAIS as the sole remaining potential CWM hazard is an Educational Awareness and Training program with CWM Project Closeout. Educational Awareness and Training materials will be posted on a public access website at: **https://www.denix.osd.mil/denix/Public/Library/Explosives/UXOSafety/uxosafety.html.**

PART I

REMEDIAL INVESTIGATION

SECTION 1
REMEDIAL INVESTIGATION INTRODUCTION

1.1. AUTHORIZATION

1.1.1. Parsons Infrastructure & Technology Group, Inc. (Parsons) was contracted by the U.S. Army Engineering and Support Center, Huntsville (USAESCH), under Contract DACA87-00-D-0038, Delivery Order 27, to conduct the Chemical Warfare Materiel (CWM) Scoping and Security Study. The objectives of the CWM Scoping and Security Study (CWM Study) were to prioritize the Formerly Used Defense Site (FUDS) eligible suspect CWM project properties (suspect CWM sites) for future funding and actions; involve the public, federal, state, tribal, and local stakeholders in the decision process for determining potential further action; and identify security and safety concerns. As discussed in the CWM Scoping and Security Study Report, the process for evaluating the suspect CWM sites was developed in a manner consistent with FUDS Program Policy (ER 200-3-1) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process guidance.

1.1.2. The CWM Study identified a group of sites where, according to historical records, the only potential CWM concern remaining at the site was Chemical Agent Identification Sets (CAIS). CAIS were expendable training aids used by the U.S. military for training personnel in the identification and decontamination of the chemical agents and industrial chemicals used in chemical warfare. CAIS consist of small glass containers filled with chemical agent and industrial chemical samples. Until recently, all CAIS have been classified as CWM. However; effective April 23, 2007, the September 5, 1997, *Interim Guidance for Biological Warfare Material (BWM) and Non-stockpiled CWM Response Activities*, as amended, was changed to allow CAIS that contain dilute chemical agents or industrial chemicals to be treated as hazardous waste, see Appendix A. Once determined to contain dilute chemical agents or industrial chemicals, CAIS, with the exception of the CAIS containing dilute nerve agent or neat chemical agent, are no longer considered chemical agent material or CWM for the purpose of storage, treatment, or disposal. CAIS that contain neat chemical agent (CAIS K941 and K942 sets) and any CAIS found to contain dilute nerve agent (K945 sets) will continue to be managed as CWM. The Site Inspection (SI) Reports prepared for these sites under the CWM Study addressed the safety and security issues regarding the past use of CWM and made recommendations based on available information and from previous investigations conducted at each site. For these sites where CAIS is the sole type of potential CWM hazard remaining, including sites where a removal action has been completed, the recommendation of the SI Report was to conduct a Programmatic Remedial Investigation/Feasibility Study (RI/FS).

1.2. PURPOSE OF REPORT

1.2.1. The purpose of this Programmatic RI/FS, is to provide the background information needed in support of an approach for selecting a response action for the sites where CAIS is the sole type of potential CWM. Since historical records are incomplete for these sites and do not include information on the final disposition of the CAIS, there is a remote chance that buried CAIS may remain in portions of the property that remain undeveloped. The Programmatic RI/FS also presents background information regarding previous investigations at CAIS sites; presents the technological limitations of locating CAIS; evaluates the contaminant fate and transport of the chemical agents and industrial chemicals in CAIS; presents a risk evaluation of both human health and the environment; and evaluates potential remedial action alternatives for the site.

1.3. APPLICABILITY

1.3.1. This document will be used to support decisions for sites where the only form of potential CWM is CAIS. This document was developed in the form of an RI/FS for FUDS, is consistent with CERCLA, and will be directly applicable to similar sites with active facilities or facilities undergoing Base Realignment and Closure (BRAC). Thus, the document is applicable to both CERCLA and Resource Conservation and Recovery Act (RCRA) sites. Figure 1.1 shows how the Programmatic RI/FS fits into the CERCLA and RCRA processes. Site-specific information will be used in combination with this document to recommend a remedy for CAIS sites.

1.3.2. Sites currently or formerly under the control of the Department of Defense (DoD) may be considered for applicability if they are under the FUDS or BRAC programs or if they are active facilities. Figure 1.2 shows a decision tree for determining if a site is applicable. This Programmatic RI/FS is applicable for a site if all of the following criteria are met:

1. The site has been determined to have had chemical warfare training using CAIS.
2. CAIS are the only potential CWM suspected to remain at the site.
3. No specific CAIS burial locations are known or suspected for the site.
4. A removal action has been completed for known CAIS burial locations.
5. CAIS have not already been addressed in previous studies that have resulted in an agreement with regulators as to what action should be taken.

1.3.3. A site is determined to be a suspect CWM site based on evaluation of the site's history and by investigations conducted for the site. Information from studies such as the Inventory Project Report (INPR), Archives Search Report (ASR), or the CWM Scoping and Security Study Report can be used to categorize a site. A site cannot be categorized as a CWM site solely based on past presence of CAIS. Note that some sites may have had CWM at one time but are considered to no longer have CWM remaining based on historical documentation, removal or cleanup of CWM, or further evaluation.

Sites that are not considered to have CWM remaining may have other hazards that need to be addressed such as munitions and explosives of concern (MEC) or hazardous and toxic wastes (HTW).

1.3.4. Suspect CWM sites may have several types of CWM remaining as potential hazards. The types of CWM include chemical munitions, bulk chemical agent stored in drums or cylinders, or CAIS containing neat chemical agent. Only sites categorized as suspect CWM sites that have CAIS as the sole remaining potential CWM hazard are considered applicable for inclusion under this Programmatic RI/FS. This includes sites where CAIS have been discovered and a removal action has been completed. Sites with other types of CWM may need to be considered for further investigation under the appropriate stage of the CERCLA or RCRA processes.

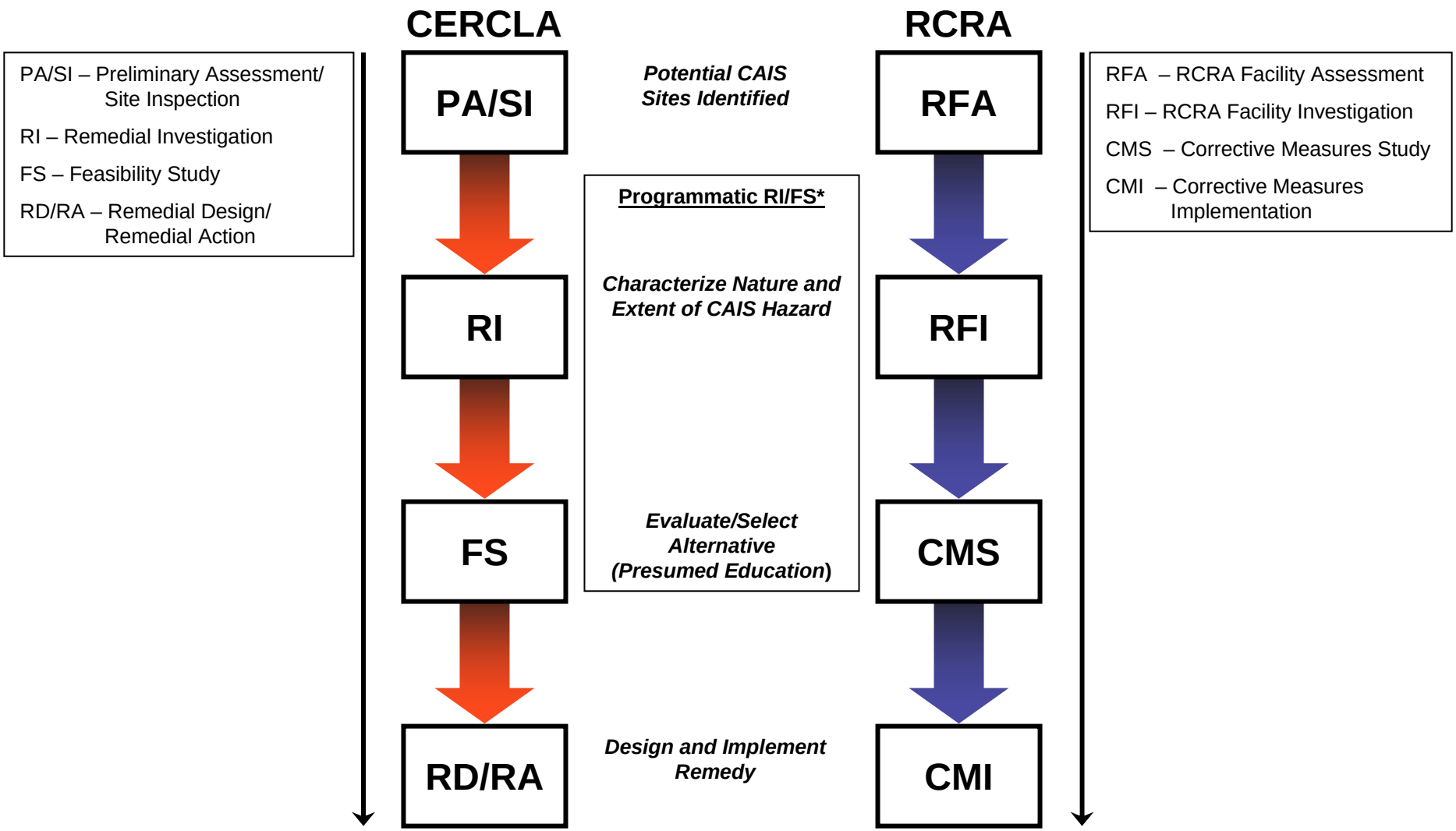
1.3.5. Some suspect CWM sites that have only CAIS as the potential remaining CWM have had specific CAIS burial locations identified. Sites with known or suspected CAIS burial locations should be considered for further investigation. A known or suspected burial is defined based on historical documentation, such as written records, corroborating witnesses, or as a result of encountering a CAIS disposal site. The basis for conducting an investigation must be stronger than relying on a statement suggesting that the named location was the most logical place for a burial. Once an investigation of a burial site has been conducted and CWM is not found or all CWM found has been removed, the site may become eligible as a site with potential CAIS remaining. Only sites where CAIS were used but do not have a known or suspected CAIS burial location, or sites where a removal action has been conducted for CAIS are eligible for inclusion under this Programmatic RI/FS.

1.3.6. Some of the sites that meet the first three criteria for inclusion under the Programmatic RI/FS may already have investigations which address CAIS hazards at the site. If an existing recommendation for a remedy has been approved or is in the final stages of approval, the site should proceed with the existing recommendation and not be included under this Programmatic RI/FS.

1.3.7. Sites that meet all five of the criteria described in paragraph 1.3.2 and illustrated in Figure 1.2 should be considered applicable to the approach outlined in this document. If new information becomes available or if site conditions change, the applicability of a site may also change.

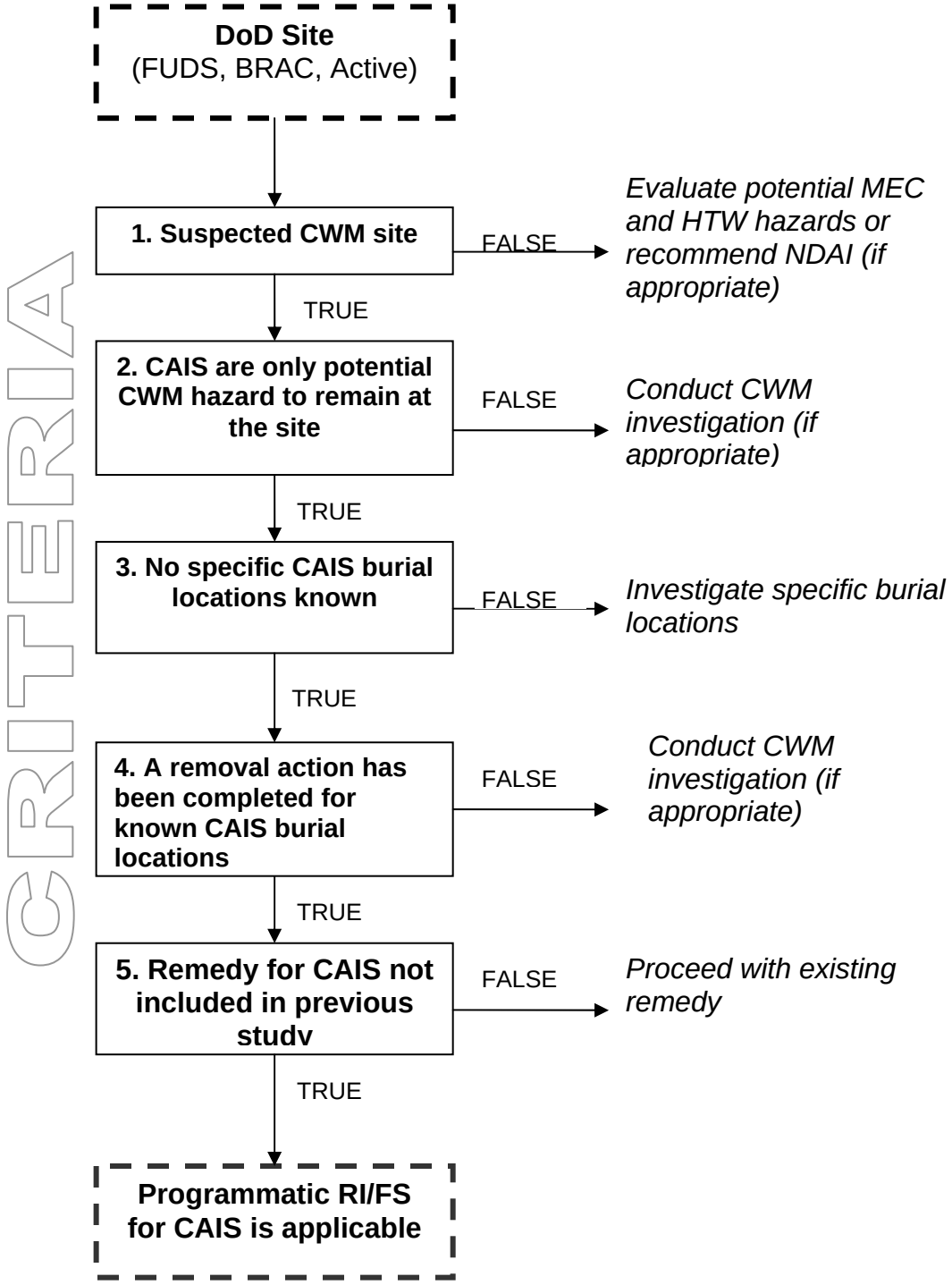
1.3.8. Each candidate site must be evaluated against the criteria in Figure 1.2. To document the applicability of the Programmatic RI/FS, it is recommended that a standardized process be used. Appendix A contains an example letter and form to use as the basis for demonstrating a site's applicability.

Figure 1.1
Programmatic RI/FS Relationship to CERCLA and RCRA Processes



*The applicability of the Programmatic RI/FS must be supported by site-specific documentation.

Figure 1.2
Site Application Decision Tree



SECTION 2
CAIS OVERVIEW

2.1. DEFINITION AND DESCRIPTION OF CAIS

2.1.1. Definition of CAIS

CAIS were expendable training aids used by the U.S. military for training personnel in the identification and decontamination of the chemical agents and industrial chemicals used in chemical warfare. CAIS consist of small glass containers filled with chemical agent and industrial chemical samples.

2.1.2. CAIS Descriptions

2.1.2.1. CAIS were known by several names including Toxic Gas Sets, Chemical Agent Identification Training Sets, Instructional War Gas Identification Sets, Detonation War Gas Identification Sets, and Instructional Gas Identification Replacement Sets. The seventeen different types of CAIS produced over the years can be grouped into three major varieties which are discussed in the following paragraphs. Table 2.1 provides additional information regarding the various CAIS. Figure 2.1 shows some of the types of CAIS.

Figure 2.1: Examples of CAIS showing (clockwise from upper left) – K941, K951, Navy X, K945

2.1.2.2. One major variety of CAIS was referred to as an instructional "sniff set" that contained glass bottles filled with chemical-impregnated charcoal, chemical-impregnated plastic pellets, or agent simulants. These sets were intended for indoors use to instruct military personnel in recognizing chemical odors. This type of set contained only small amounts of chemicals. These sets were packaged in hinged wooden boxes that resembled small foot lockers. The bottles were stored in the box in metal cans with paint-can type lids. This group included the K945, K955, and Navy X sets. The K955 sets were used from the late 1930's through World War II and were designed to be used with detection instrumentation rather than be detonated or directly handled by the students. The K945 sets were used during the late 1960's and the Navy X sets were used from World War II through the Korean War. The Navy X sets were replacements for individual components of the K955 sets. The K945 sets were not used to train troops in odor recognition; instead, they were used to train troops in the proper use of detection instruments. Because of the presence of nerve agent, the K945 sets are classified as CWM. The *U.S. Army Program Manager for Chemical Demilitarization, Chemical Agent Identification Sets (CAIS) Information Package* (DoD, 1995) states that the K945 sets were believed to have all been destroyed in disposal operations at Rocky Mountain Arsenal between 1979 through 1982. A personal communication with Mr. William Brankowitz of Aberdeen Proving Ground, MD confirmed that all of the K945 kits were accounted for and destroyed. Specific details on the "sniff sets" are presented in Table 2.1. Photos of these sets are shown in Figures 2.1 and 2.2. The CAIS "sniff sets," with the exception of the K945 sets, are classified as Hazardous and Toxic Waste and not as CWM.

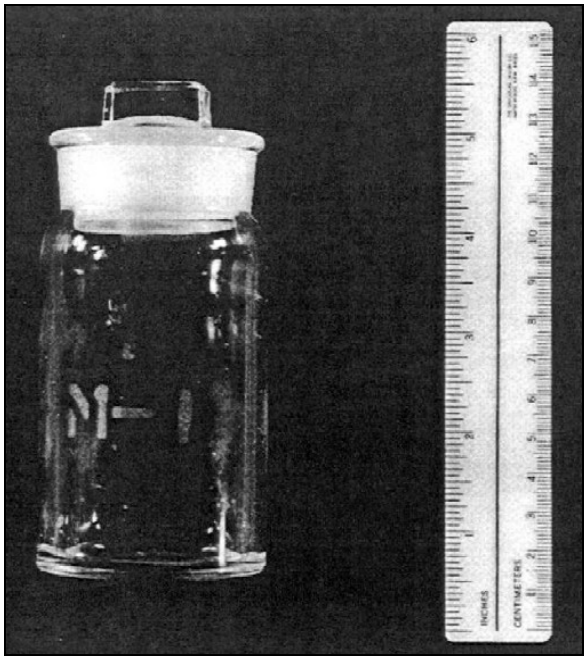


Figure 2.2: K955 or Navy X set bottle with Lewisite markings (M-1)

2.1.2.3. A second major variety of CAIS, designed for outdoor use, consisted of chemicals (pure or in solution) in sealed ampoules. The ampoules were made of shock-resistant borosilicate glass, such as Pyrex®. These ampoules were one inch in diameter and approximately 7.5 inches long. Each ampoule was packed in a cardboard screw-cap container with the chemical type indicated on the cap. Twelve cardboard containers were fit into a metal can with a press-fit lid. Four cans were stored in a steel shipping container ("pig") approximately 6.5 inches in diameter and 38 inches long. The open end of the steel container was flanged and covered with a lead gasket and a metal plate. This variety included the K951 and K952 and K953 and K954 sets. The K951 and K952 sets were used from the early 1930's to the late 1950's. The K953 and K954 sets were used in the early 1950's during the Korean War. Specifics on these sets are presented in Table 2.1. Photos of the K951 and K952 sets are shown in Figures 2.1, 2.3, and 2.4. The K 951 and K952 are stored, handled, and disposed of as Hazardous and Toxic Waste (HTW) but are still considered CWM for the purposes of investigation and identification. .

Figure 2.3: K951/K952 glass ampoule

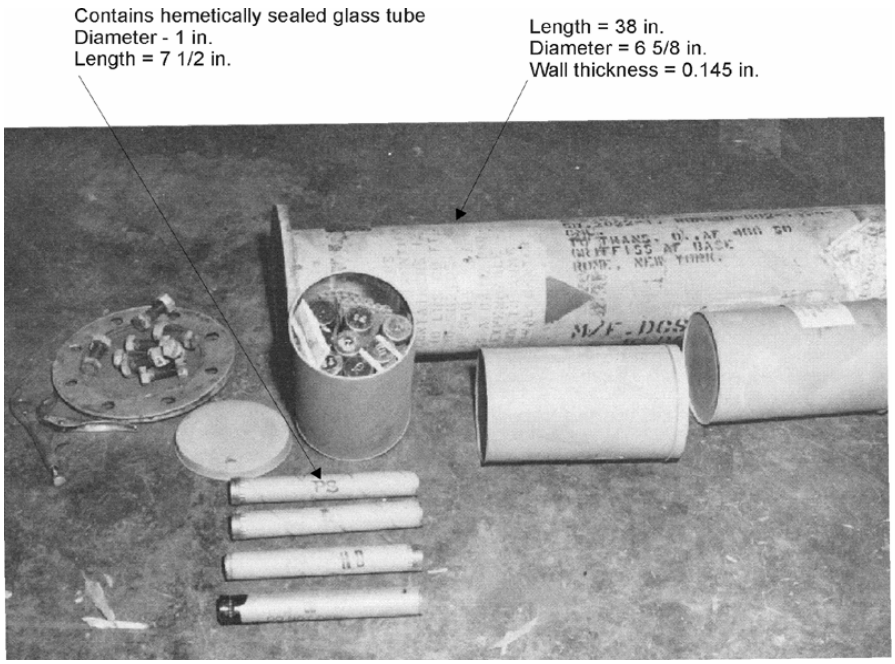


Figure 2.4: K951/K952 CAIS

2.1.2.4. A third major variety of CAIS were those containing bulk mustard in small bottles or ampoules. These CAIS were used in decontamination training by purposely contaminating terrain or equipment with mustard agent, then training the soldiers how to don the correct protective equipment and decontaminate the area or equipment. This variety included the K941 and K942 sets. The K941 sets were used from World War II to the late 1950's and the K942 sets were used in the early 1950's during the Korean War. Specific details on these sets are presented in Table 2.1. Figures 2.5 and 2.6 show the K941 set. Figure 2.7 shows the K942 set. The K941 and K942 sets are classified as CWM.

Figure 2.5: 3.5-ounce mustard (HS) bottle from K941 set

Figure 2.6: CAIS shipping container (pig) with mustard bottle and packing material, K941 set

Figure 2.7: K942 metal drum with 14 cans containing mustard ampoules

2.2. HISTORY AND USES OF CAIS

2.2.1. More than 100,000 CAIS were produced from 1928 to 1969 (U.S. Army, 1995). The military conducted a program to destroy the stockpiles of CAIS at the Rocky Mountain Arsenal from 1978 to 1982. In that program, CAIS were collected from storage depots and other military installations; as a result, the military destroyed 21,458 CAIS. It was believed that the remaining approximately 80,000 CAIS had been expended by the military during training; however, CAIS have been recovered from several FUDS as a result of construction or other intrusive operations.

2.2.2. CAIS were originally intended for training combat troops in the identification of the odor and effects of chemical agents and industrial chemicals used in chemical warfare. Soldiers were intentionally exposed to the chemicals in the CAIS to enable them to recognize the odor and effects of chemical agents and to train them to take immediate defensive action. According to the training manual, "every soldier should become proficient in identification of gases through odor and other sensory reactions, since other means may not be available".

2.2.3. During World War II, the initial stage of training consisted of classroom lectures on the properties of chemical agents. CAIS in the form of "sniff sets" were used in training to familiarize students with the odors of the various agents (Figure 2.8).

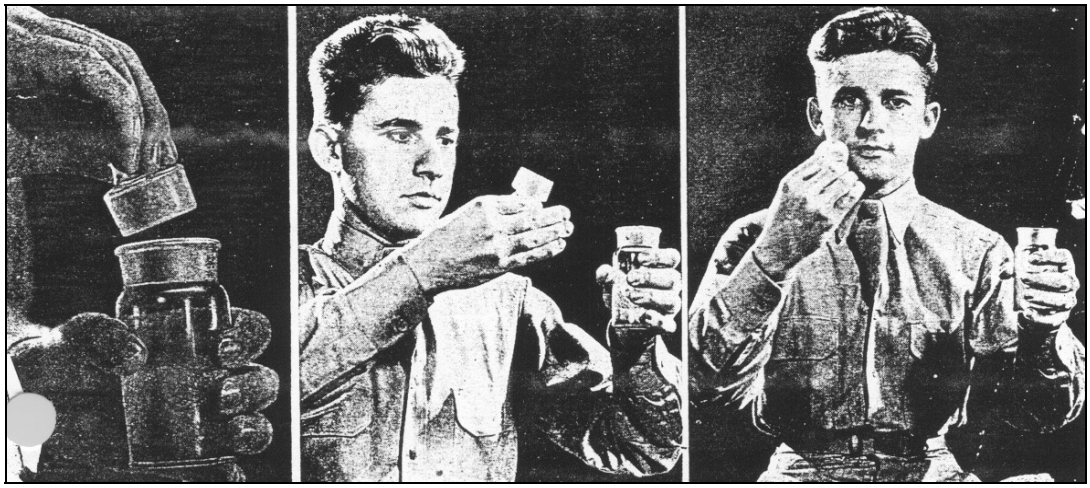


Figure 2.8: Use of Sniff Set being demonstrated

2.2.4. The next stage of familiarization training was conducted outdoors. The recommended method of training was to detonate the glass ampoules with blasting caps to atomize the chemicals and form a small aerosol cloud (Figure 2.9). The trainees were positioned downwind prior to the detonation and were instructed to allow the cloud to envelope them (or walk into the cloud), take a sniff just enough to recognize the odor, and then exit the cloud and exhale (Committee on Review and Evaluation of the Army Non-Stockpile Chemical Materiel Disposal Program, 1999). According to the training manual, four gases were detonated in succession, with an interval between gases. For effective instruction, the name of the gas was not revealed before it was detonated. The trainees were graded on their ability to identify the four gases in order and it was recommended that men who failed to identify the gases go through the exercise again. The training manual stated that "It should be made clear to them that this is an opportunity, not a penalty, for their lives may later depend on their individual judgment."

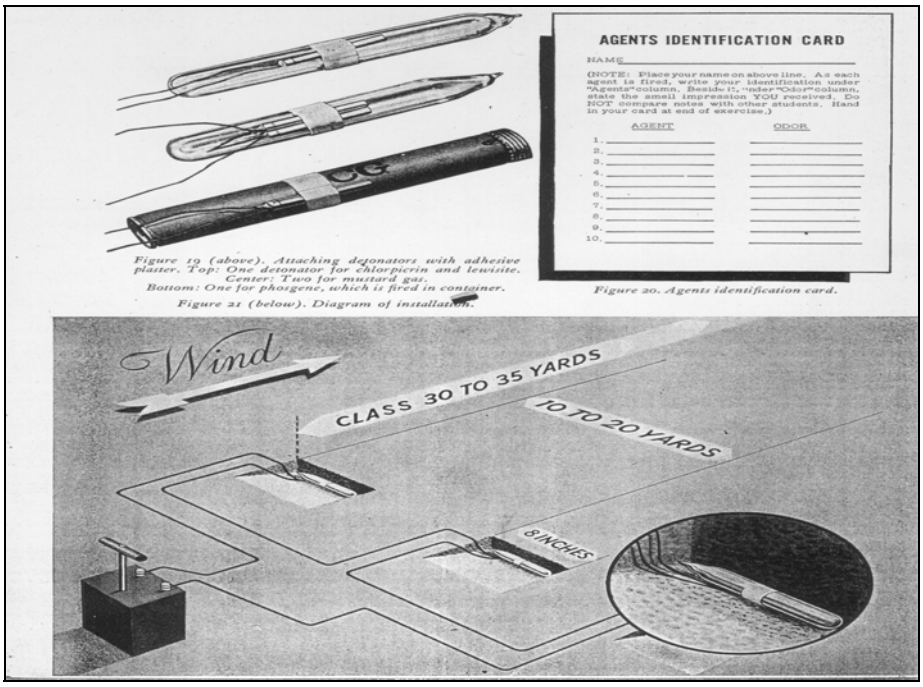


Figure 2.9: Page from training manual showing the use of K951 CAIS

2.2.5. Depending on their mission, some of the troops received additional training in decontamination procedures. This training sometimes involved the use of undiluted mustard spread on vehicles, equipment, or the ground (Figures 2.10 and 2.11). Teams of students practiced decontamination by mixing decontamination solutions and applying the mixture to the contaminated area.

Figure 2.10: Vehicle decontamination training

Figure 2.11: Ground decontamination training

2.2.6. The report titled "Review of the Army Non-Stockpile Chemical Materiel Disposal Program: Disposal of Chemical Agent Identification Sets" presented a conservative estimate of the number of trainees exposed to this training (Committee on Review and Evaluation of the Army Non-Stockpile Chemical Materiel Disposal Program 1999). The estimate was made by multiplying the number of CAIS believed to have been used during training (approximately 80,000) by the number of ampoules/bottles in each CAIS (24 to 48) for a total of 1,920,000 to 3,840,000. If two ampoules of the four agents were used in each training exercise (a total of eight ampoules per session), as described in the training manual, between 120,000 and 240,000 sessions (exposure of a class of trainees to all four chemicals) were conducted. Conservatively, assuming that each training class consisted of only five trainees, the estimated total number of trainees exposed to CAIS chemicals is 600,000 to 1,200,000. It is doubtful that a training class would consist of only five people since records indicate that one ampoule could be used to train 25 soldiers. The use of two ampoules in each training exercise suggests that training classes could have been as large as 50 persons. Also, each training class would likely expend ampoules of each type of agent (4 or 6 types depending on the type of CAIS).

2.3. DISPOSAL OF CAIS

As a result of the outdoor training activities, there is a chance that ampoules that did not break during the blasting cap detonation or that otherwise unused ampoules or bottles were disposed of at the training areas. Disposal of full bottles and ampoules onsite would have been an unusual occurrence, since most of the CAIS bottles and ampoules were consumed in training. Unused bottles and ampoules were normally returned to the

storage area. Disposal of CAIS from "sniff sets" would have been more uncommon since these sets were used and reused in the classroom. Intentional burial of CAIS as a means of disposal was an accepted practice and is known to have occurred at some sites. At the end of World War II, facilities were encouraged to destroy some training materials, such as CAIS, in the interest of public safety. In such instances, the CAIS were usually destroyed by burning in a pit and mixing the remains with decontaminants as the pit was backfilled. In other cases, CAIS were simply buried, often with other discarded items (Chemical Warfare Service, 1946). Disposal by burial could occur at almost any location on an installation; examples of known burials are near the ordnance area, in the chemical warfare training area, at small arms ranges, and near landfill sites. As a result of disposal by burial, glass CAIS ampoules or bottles may be found buried directly in soil, buried within their shipping containers, or buried adjacent to their packaging materials or shipping containers.

2.4. QUANTITY OF CAIS USED

2.4.1. Detailed information regarding the production and distribution of CAIS is unavailable. The numbers and types of CAIS sent to individual sites as well as the timing for shipments is unknown. General information is available about how the various components (bottles, ampoules, packing material, shipping containers, etc.) were manufactured, assembled, filled with chemical agents and industrial chemicals, and then shipped to depots for distribution to training facilities.

2.4.2. Estimates of the amounts of chemicals consumed in training can be made based on class sizes and the numbers of troops trained at typical sites. The amounts of chemicals consumed have been estimated for three main types of facilities. The types of facilities are:

- Airfields (Army Airfields and Naval Air Stations),
- Troop training centers (Army forts and camps and Naval training bases), and
- Storage depots (including some arsenals).

Table 2.2 shows the estimates for the amounts of chemicals consumed during training for World War II and the Korean War.

2.4.3. The distribution of CAIS varies among facility types due to the numbers of troops trained and the types of training conducted. For instance, airfields had approximately 1,200 military personnel at any given time during World War II. All of the personnel would have been trained using instructional and detonating CAIS once per year. In addition to the general training in agent identification, a portion of military personnel would have had more extensive training in chemical warfare operations. At Army airfields, the additional training would have been given to personnel (approximately 10% to 15% of the total) who were assigned to air operations chemical companies, aviation depot companies, and aviation maintenance companies. Some of the troops undergoing additional training would have been sent to Edgewood Arsenal or

Camp Sibert for their training but others would have been trained directly at the airfield or received refresher training at the airfield.

2.4.4. Based on the above information, the following estimates can be made for a typical Army airfield for 5 years of operation during World War II (1941 through 1945). Table 2.2 provides a summary of the information:

- Training manuals at the time indicate that a single K951 ampoule would be used for 25 troops (TM 3-305, 1944). Training all personnel once per year for five years in outdoor agent identification using K951 CAIS would consume:
    - 480 mL H (0.13 gallons).
    - 480 mL L (0.13 gallons).
    - 4800 mL PS (1.3 gallons).
    - 9600 mL CG (2.5 gallons).
    - 23,040 mL (6.1 gallons) chloroform (contributed from H, L and PS ampoules).
- Assuming the same class size of 25 for decontamination training, 1 bottle of H would be consumed per class for 8 classes per year (8 bottles per year – 40 bottles in 5 years). With each bottle containing 3.5 ounces or 103.5 mL of H, 4,140 mL (1.1 gallons) would be consumed over the five years.
- While there are no statistics on the rate of consumption of the "sniff sets," the assumption is that they lasted a long time before needing replacement. Replacements could be in the form of new K955 sets or from X Sets used to replace individual chemicals that had run out. Assuming that one set would be consumed in a year of classroom training, the following amounts of chemicals would have been consumed in five years:
    - 125 mL H (0.03 gallons)
    - 125 mL L (0.03 gallons)
    - 125 mL PS (0.03 gallons)
    - 30 g triphosgene (0.07 pounds)
    - 75 g CN (0.16 pounds)
    - 75 g DM (0.16 pounds)
    - 125 mL (0.03 gallons) HN-1 (assuming X Sets were used for this agent)
    - 125 mL (0.03 gallons) HN-3 (assuming X Sets were used for this agent)

  These chemicals would largely be lost to gradual volatilization, although there could have been some loss from accidental spillage. Quantities of CN

and DM may be overestimated since in reality these solid chemicals do not readily volatilize.

- Combined usage of all types of CAIS at a typical Army airfield would result in the consumption of:
    - 4,745 mL H (1.3 gallons)
    - 605 mL L (0.2 gallons)
    - 4,925 mL PS (1.3 gallons)
    - 9,600 mL CG (2.5 gallons)
    - 23,040 mL chloroform (6.1 gallons)
    - 30 g triphosgene (0.07 pounds)
    - 75 g CN (0.16 pounds)
    - 75 g DM (0.16 pounds)
    - 125 mL HN-1 (0.03 gallons)
    - 125 mL HN-3 (0.03 gallons)

2.4.5. The amounts of chemicals shown above represent the consumption at a typical Army airfield. Facilities such as Army forts and camps would have trained 10 to 20 times as many troops, so the amounts of chemicals used at those facilities would have increased proportionately. Troop training using CAIS at storage depots involved numbers of troops similar to the Army airfields, so the amounts of chemicals used at depots would be similar to the list above.

2.4.6. The United States was involved in the Korean War from summer 1950 to summer 1953. During that time, many training installations in the United States that had been closed following World War II were reopened. The training conducted was similar to that of World War II; however, new types of CAIS were used. While some training was probably still conducted using the K951 sets, the newer K953 sets were also used. The chemicals in the K953 sets consisted of H, HN-1, L, CG, and CK. A simulant for the nerve agent GA was also used. These K953 sets were detonated similar to the K951 sets. Decontamination training was also conducted using either the K941 sets or the K942 sets, which contained similar amounts of mustard (H). K955 “sniff sets” were probably used along with replacement chemicals from the X Sets.

2.4.7. Training in chemical agent identification continued at a slower pace in the years after the Korean War using the sets produced during that war and World War II. Only from the late 1960s through 1971 were new types of CAIS introduced. These sets, K945 (M72) and the simulant M72A1 set, were designed to be used with detection instrumentation rather than be detonated or directly handled by the students.

2.4.8. Many of the chemicals in CAIS are highly volatile and others degrade at the ground surface. The amounts consumed do not reflect the amounts potentially remaining at a site. Section 5 includes a discussion of the environmental fate and transport of the various chemicals found in CAIS. The important conclusion in analyzing the estimated amount of chemicals used is that these chemicals were used in amounts numbering in liters and tenths of liters.

Table 2.1
Types and Components of Chemical Agent Identification Sets (CAIS)

CAIS Type	Description	Packaging	Contents		
			Chemical Type	No. of Containers	Volume Per Container
K945	M72 Chemical Agent Identification Training Set (designed to be used with detection instrumentation rather that be detonated or directly handled by the student).	8 square bottles and 3 small round bottles enclosed in a 12-inch by 5.5-inch by 4-inch gray polystyrene carrying case weighing 3 pounds. The plastic case is sealed in two-layer laminated plastic bags that are packed in a fiberboard box. The fiberboard box is packed in a wooden box sealed with metal straps. Then entire box weighs about 11 pounds.	Sarin (GB)	4	21 mL absorbed in plastic pellets.
			Lewisite (L)	1	21 mL absorbed in plastic pellets.
			Triphosgene*	1	21 mL absorbed in plastic pellets.
			Potassium Cyanide (KCN)	1	21 mL absorbed in plastic pellets.
			Mustard (H)	1	21 mL absorbed in plastic pellets.
			Simulant	3	unknown

* - Triphosgene is a phosgene simulant.

Table 2.1
Types and Components of Chemical Agent Identification Sets (CAIS)

CAIS Type	Description	Packaging	Contents		
			Chemical Type	No. of Containers	Volume Per Container
K955	CAIS "Sniff Set" – M1 Instructional Gas Identification Set (Navy)	These sets are packed in a hinged covered wood box that resembles a foot locker and measures 30 3/8 inches wide, 15½ inches long and 11¾ inches wide. The inside of the box is divided into 8 sections. Seven of the sections contain sealed metal cans in sawdust and the eighth has instructions. The cans are 4 inches in diameter and 7 inches high and have paint can-type lids. Inside each can is one round bottle with a large screw top or glass stopper which is usually glass coated. The bottles are frequently filled with charcoal. The filled wooden box weighs about 71 pounds.	Mustard (HS)	2	25 mL absorbed on 90cc of charcoal
			Lewisite (L or M-1)	1	25 mL absorbed on 90cc of charcoal
			Chloropicrin (PS)	1	25 mL absorbed on 90cc of charcoal
			Triphosgene*	1	6 grams
			Chloroacetophenone (CN)	1	15 grams
			Adamsite (DM)	1	15 grams

* - Triphosgene is a phosgene simulant.

Table 2.1
Types and Components of Chemical Agent Identification Sets (CAIS)

CAIS Type	Description	Packaging	"X Set"	Contents		
				Chemical Type	No. of Containers	Volume Per Container
Navy X Sets (9 types)	CAIS "Sniff Set" – Instructional Gas Identification Replacement Set	As described for the K955 set, the bottles were packaged in cans. Two cans were shipped in wooden boxes 16 inches long by 7½ inches wide by 11¾ inches high. Each box with two cans weighs about 17 pounds.	X302	Nitrogen Mustard (HN-1)	1	25 mL
				Nitrogen Mustard (HN-3)	1	25 mL
			X545	Triphosgene*	2	3 grams
			X546	CN	2	15 grams
			X547	HS	2	25 mL in charcoal
			X548	L	2	25 mL in charcoal
			X549	DM	2	15 grams
			X550	HN-1	2	25 mL in charcoal
			X551	HN-3	2	25 mL in charcoal
			X552	PS	2	25 mL in charcoal

*Triphosgene is a phosgene simulant.

Table 2.1
Types and Components of Chemical Agent Identification Sets (CAIS)

CAIS Type	Description	Packaging	Contents		
			Chemical Type	No. of Containers	Volume Per Container
K951/K952	CAIS for outdoor identification training – M1 Instructional War Gas Identification Set	48 Pyrex®, flame-sealed, 7.5-inches by 1-inch ampoules. Each ampoule is packed in a cardboard screw cap container with agent type indicated on the cardboard container. Twelve cardboard containers each are packaged into 4 press fit metal cans 9¼ inches high. The cans are packed into a steel cylinder 6 5/8 inches in diameter, approximately 38 inches long, and 0.145 inches thick. The open end of the cylinder is closed by a flanged end cover which is secured by eight bolts. The only difference between the K951 and K952 is that the K951 was issued with blasting caps that were packed and shipped in a separate container. A shipping container weighs about 110 pounds when full.	H	12	2 mL of H diluted with 38 mL of chloroform.
			L	12	2 mL of L diluted with 38 mL of chloroform
			PS	12	20 mL of PS and 20 mL of chloroform
			Phosgene (CG)	12	40 mL

Table 2.1
Types and Components of Chemical Agent Identification Sets (CAIS)

CAIS Type	Description	Packaging	Contents		
			Chemical Type	No. of Containers	Volume Per Container
K953/K954	CAIS for outdoor identification training – AN-M1A1 Instructional War Gas Identification Set	48 Pyrex®, flame-sealed, 7.5-inches by 1-inch ampoules. Each ampoule is packed in a cardboard screw cap container with agent type indicated on the cardboard container. Twelve cardboard containers each are packaged into 4 press fit metals cans 9¼ inches high. The cans are packed into a steel cylinder 6 5/8 inches in diameter, approximately 38 inches long, and 0.145 inches thick. The open end of the cylinder is closed by a flanged end cover which is secured by eight bolts. The only difference between the K953 and K954 is that the K953 was issued with blasting caps that were packed and shipped in a separate container. A shipping container weighs about 110 pounds when full. Note: a modified version of the K953/K954 sets contained only H, L, CK, and CG ampoules.	H	8	2 mL of H diluted with 38 mL of chloroform.
			HN-1	8	4 mL of HN-1 diluted with 36 mL of chloroform
			L	8	2 mL of L diluted with 38 mL of chloroform
			CG	8	40 mL
			Cyanogen Chloride (CK)	8	40 mL
			GA simulant*	8	40 mL

* - diethyl malonate

Table 2.1
Types and Components of Chemical Agent Identification Sets (CAIS)

CAIS Type	Description	Packaging	Contents		
			Chemical Type	No. of Containers	Volume Per Container
K941	CAIS used for decontamination training – M1 Toxic Gas Set	24 round screw-top bottles with heat resistant paint indicating the contents. Four bottles are packed in a one-half inch layer of sawdust within a sealed metal can. The cans are pressure sealed, 6¼ inches high, and have a sardine-type key on the bottom. Six of these cans are placed into a steel shipping cylinder that is 6-5/8 inches in diameter, approximately 38 inches long, and 0.145 inches thick. The open end of the cylinder is closed by a flanged end cover which is secured by eight bolts. A shipping container weighs about 110 pounds when full.	H, HS or HD	24	3.5 ounces
K942	CAIS used for decontamination training – M2/E11 Toxic Gas Set	28 heat-sealed ampoules, 1-7/8 inches in diameter and 4-5/8 inches in length. Each ampoule is stored in a hermetically sealed tinplate tearstrip metal container. There are 14 metal containers in each of 2 hexagonal fiberboard containers are packed in a 14-inch diameter carbon steel (20-gauge) drum, 14 inches height. The drum was sealed by a bolted ring-closure cover seated on a rubber gasket. The drum is painted gray with two green bands. A shipping container weighs about 110 pounds when full.	H, HS, or HD	28	3.8 ounces (112.5 mL)

Table 2.2
Estimates of CAIS Chemicals Consumed

World War II	**Typical Army Airfield**				**Typical Army Fort or Camp**				**Training at Typical Storage Depot**			
Years of Operation	5 (1941-1945)				2 (1941-1945)				5 (1941-1945)			
Troops Trained (per year)	1200	1200	180		12000	12000	1800		1200	1200	180	
Total No. of Sets Used	5	20	1 2/3		6	80	6		5	20	1 2/3	
	"sniff sets" K955 / X (mL)	**Detonating K951/K952** (mL)	**Decon K941** (mL)	**Total** (mL)	**"sniff sets" K955 / X** (mL)	**Detonating K951/K952** (mL)	**Decon K941** (mL)	**Total** (mL)	**"sniff sets" K955 / X** (mL)	**Detonating K951/K952** (mL)	**Decon K941** (mL)	**Total** (mL)
H	125	480	4140	4745	150	1920	14904	16974	125	480	4140	4745
L	125	480	-	605	150	1920	-	2070	125	480	-	605
HN-1	125	-	-	125	150	-	-	150	125	-	-	125
HN-3	125	-	-	125	150	-	-	150	125	-	-	125
PS	125	4800	-	4925	-	19200	-	19200	125	4800	-	4925
CG	-	9600	-	9600	-	38400	-	38400	-	9600	-	9600
CK	-	-	-	-	-	-	-	-	-	-	-	-
diethyl malonate (GA-sim)	-	-	-	-	-	-	-	-	-	-	-	-
chloroform	-	23040	-	23040	-	92160	-	92160	-	23040	-	23040
triphosgene	30 g	-	-	30 g	35g	-	-	35g	30 g	-	-	30 g
CN	75 g	-	-	75 g	90g	-	-	90g	75 g	-	-	75 g
DM	75 g	-	-	75 g	90g	-	-	90g	75 g	-	-	75 g

Korean War	**Typical Army Airfield**				**Typical Army Fort or Camp**				**Training at Typical Storage Depot**			
Years of Operation	3 (1950-1953)				3 (1950-1953)				3 (1950-1953)			
Troops Trained (per year)	1200	1200	180		12000	12000	1800		1200	1200	180	
Total No. of Sets Used	3	18	22/28		6	80	6		3	18	22/28	
	"sniff sets" K955 / X (mL)	**Detonating K953/K954** (mL)	**Decon K942** (mL)	**Total** (mL)	**"sniff sets" K955 / X** (mL)	**Detonating K953/K954** (mL)	**Decon K942** (mL)	**Total** (mL)	**"sniff sets" K955 / X** (mL)	**Detonating K953/K954** (mL)	**Decon K942** (mL)	**Total** (mL)
H	75	288	2473	2836	150	1280	14904	16334	75	288	2473	2836
L	75	288	-	363	150	1280	-	1430	75	288	-	363
HN-1	75	576	-	75	150	2560	-	2710	75	576	-	75
HN-3	75	-	-	75	150	-	-	150	75	-	-	75
PS	75	-	-	75	150	-	-	150	75	-	-	75
CG	-	5760	-	5760	-	25600	-	25600	-	5760	-	5760
CK	-	5760	-	5760	-	25600	-	25600	-	5760	-	5760
diethyl malonate (GA-sim)	-	5760	-	5760	-	25600	-	25600	-	5760	-	5760
chloroform	-	16128	-	16128	-	71680	-	71680	-	16128	-	16128
triphosgene	25 g	-	-	25 g	35g	-	-	35g	25 g	-	-	25 g
CN	45 g	-	-	45 g	90g	-	-	90g	45 g	-	-	45 g
DM	45 g	-	-	45 g	90g	-	-	90g	45 g	-	-	45 g

SECTION 3
INVESTIGATION OF CAIS SITES

3.1 INTRODUCTION

This section presents a discussion of previous investigations conducted at FUDS as a result of accidental discovery of CAIS items remaining on-site due to past destruction activities, burial or abandonment. These case histories represent possible scenarios for disposal at other installations with CAIS at the end of World War II. The scenarios document how CAIS have been accidentally encountered and how investigations were conducted to find and remove CAIS hazards. In addition, this section discusses the detection methods and the limitations of the methods that may be used to locate buried CAIS. Both direct and indirect detection methods are discussed in this section.

3.2 PREVIOUS INVESTIGATIONS

Since records regarding the disposition of the CAIS used and stored at many of the facilities are incomplete, predicting if, when, or where a CAIS item may be discovered is virtually impossible. The accidental discovery of CAIS or CAIS items is rare; however, the consequences can be serious without knowing what precautionary measures to take. There have been several recorded instances where someone has either found or dug up a CAIS item. Details of these instances are presented in the following sub-sections.

3.2.1 Fort Crowder, Missouri

3.2.1.1. During World War II, field demonstrations were conducted to train troops in gas mask proficiency and in the familiarization of various war gases using CAIS. The former Pistol Ranges and the No. 110 Gas Chamber Area were described as the Chemical Exercise Area but no boundaries were identified (Parsons, 2005a). It was reported that chemicals were stored in Quonset huts, or igloos, located in the vicinity of the Chemical Exercise Area. After World War II, these structures were declared surplus and sold. Reportedly, the work crews removing the igloos took anything found in the structures, dumped it out nearby, and buried it (Parsons, 2005a).

3.2.1.2. In June 1986, a bulldozer operator preparing a site for new building construction uncovered several ampoules containing unidentified liquid and some metallic material of military nature. A white gaseous cloud filled the air behind the bulldozer after it ran over some of the ampoules. The operator's eyes became watery and he had difficulty breathing. After resting for a while the operator went back to work and did not report the incident until the following day (Parsons, 2005a). The U.S. Army

Technical Escort Unit (TEU) responded and removed the following military-related debris:

- 40 M1 practice mine fuzes,
- 8 M1 practice mine fuze components,
- 15 M48 surface trip flares (without fuzes),
- 3 M10 Mk2 practice grenade fuzes,
- 1 M11 aircraft signal, and
- 30 40 ml (1.4 ounces) glass ampoules containing chemical agent or industrial chemicals, along with some packing material (9 were confirmed as components of K951 CAIS; according to the TEU Trip Report, three of the ampoules contained mustard (Parsons, 2005a).

3.2.1.3. TEU carefully cleared the site of munitions and ampoules by sifting the loose dirt moved by the bulldozer. An 8-inch layer of soil was removed and sifted and the area was decontaminated with calcium hypochlorite (Parsons, 2005a).

3.2.1.4. In 2003, the USAESCH conducted a site investigation to characterize the potential presence of CWM contamination at the former Fort Crowder. The No. 110 Gas Chambers Area and the former Pistol Ranges area were the focus of the investigation. The area of the 1986 exposure incident was within the investigation area. The investigation activities included geophysical surveys, anomaly reacquisition, air monitoring, intrusive operations, and soil sampling and analysis.

3.2.1.5. A geophysical survey was conducted over approximately 30 acres in the former Pistol Range and No. 110 Gas Chambers Area. Evaluation of the geophysical data identified 113 “pig-like” anomalies. The individual metal shipping containers (or pigs) possibly containing glass CAIS ampoules were expected to have metal detector anomaly amplitudes in excess of 10 mV and were classified as “high priority” anomalies. A total of 137 “high priority” anomalies were identified through evaluation of the geophysical data. An additional 98 “high amplitude, non-pig-like” anomalies were also identified for investigation through evaluation of the geophysical data. A part of the berm that once was part of the former Pistol Range remained onsite. The berm was inspected using Schonstedt magnetic locators and 144 anomalies were flagged for investigation on the berm using the magnetic locators. In addition to the individual anomalies identified for potential investigation, 10 anomalous areas consistent with burial trenches or pits were identified for investigation from the geophysical survey (Parsons, 2005a).

3.2.1.6. Intrusive sampling included hand-tool excavation and backhoe trenching to evaluate the potential presence of CWM. Edgewood Chemical Biological Center (ECBC) personnel performed continuous air monitoring of downrange air quality during excavations. The air was monitored for chemical agents and industrial chemicals during excavation activities using the Miniature Chemical Agent Monitoring System (MINICAMS) and the Depot Area Agent Monitoring System (DAAMS). Subsurface soil samples were collected and submitted for laboratory analysis during the intrusive

investigation. Samples were collected from the bases of excavated trenches and from trench side walls and were analyzed for select chemical agents and their chemical agent breakdown products (ABP).

3.2.1.7. Intrusive investigation activities were conducted from November 3, 2003 through November 20, 2003. The number of anomalies investigated was reduced in some cases based on the findings of the initial digs and a review of the geophysical data (e.g., metallic sources of the anomalies were much smaller than steel pigs). The anomalies investigated consisted of all 137 "high priority" anomalies; 49 of the 113 "piglike" anomalies; 39 of the 98 "high amplitude, non-piglike" anomalies; 34 of the 144 "mag and flag" anomalies from the berm; and the 10 anomalous areas identified during the geophysical survey (Parsons, 2005a).

3.2.1.8. The intrusive investigation activities conducted at the former No. 110 Gas Chambers Area and the former Pistol Range Area did not uncover any CWM or chemical agent contaminated media. Military related items found during the investigation included a live practice mine fuze and ordnance-related scrap from two rifle grenades. The live practice mine fuze was located in the former Pistol Range Area, approximately 40 feet southeast of the 1986 incident area. This item was relocated next to the berm and blown-in-place by a U.S. Army Explosives Ordnance Disposal unit from Fort Leonard Wood. The remainder of the items recovered during the intrusive investigation activities consisted primarily of metal items consistent with building materials and farm activities. These items included barbed wire, banding material, nails, rebar, tool parts, wire, nuts, bolts, and pieces of reinforced concrete (Parsons, 2005a).

3.2.1.9. Thirty soil samples were collected from the trenches during the investigation of the anomalous areas at the former Fort Crowder. Headspace monitoring of the samples for chemical agents was conducted by ECBC. Since all soil samples were non-detect for chemical agent, the samples were shipped to the ECBC laboratory at the Edgewood Arsenal in Aberdeen Proving Ground, Maryland for further analysis. The soil samples were analyzed for mustard (H); nitrogen mustards (HN-1 and HN-3); Lewisite (L); and their corresponding ABPs. No chemical agents or breakdown products were detected in the ECBC laboratory analyses (Parsons, 2005a).

3.2.1.10. Air monitoring results for the MINICAMS and DAAMS were non-detect for chemical agents during the intrusive activities conducted at the former Fort Crowder (Parsons, 2005a).

3.2.1.11. In the case of the former Fort Crowder, the CAIS items were originally discovered during construction activities in 1986. Although the intrusive investigation conducted in 2003 located no CAIS items associated with the subsurface metallic objects, the possibility remains that additional ampoules are located at the site but cannot be located due to the inability to detect buried glass using current geophysical technology.

3.2.2 Harvard Target Range, Nebraska

3.2.2.1. Chemical warfare training for the air and ground crews stationed at Harvard AAF was conducted at the nearby target range. The designated chemical training area at the target range overlapped with some of the small arms ranges (Parsons, 2006). Similar to Santa Rosa AAF and other airfields, training consisted of agent identification and decontamination training. When the Harvard AAF closed in 1946, the Mustard Training Area was used as the disposal site for the remaining drums of mustard and CAIS (Parsons, 2006). Two rounds of decontamination were required. By 1947, the odor of mustard still lingered at the site but no further decontamination was conducted. In 1997, the landowner encountered two empty steel pigs while plowing the field. He claimed that more pigs might be present (Parsons, 2006).

3.2.2.2. In 2004, the USAESCH conducted a site investigation of the Mustard Training Area to characterize the potential presence of CWM contamination at the former Harvard Target Range (TR). The investigation activities included geophysical surveys, anomaly reacquisition, air monitoring, intrusive operations, and soil sampling and analysis.

3.2.2.3. A geophysical survey was conducted over approximately 30 acres in the former Mustard Training Area. The primary target of the investigation was the CAIS shipping container (pig). The pigs are approximately 38 inches in length and are expected to have anomaly amplitudes in excess of 50 mV. A total of 57 anomalies, 11 quality assurance (QA) anomalies, and 4 anomalous areas were selected for investigation (Parsons, 2006). The individual anomalies with the characteristics closest to the CWM shipping containers were classified as high priority. A total of 17 high priority anomalies and 40 low priority anomalies (non-pig-like) were identified through evaluation of the geophysical data. The 11 QA anomalies were used to confirm the anomaly selection process by including anomalies otherwise excluded for investigation (Parsons, 2006).

3.2.2.4. Intrusive sampling included hand-tool excavation and backhoe trenching to evaluate the potential presence of CWM. ECBC personnel performed continuous air monitoring of downrange air quality during excavations. The air was monitored for chemical agents and industrial chemicals during excavation activities using MINICAMS and DAAMS tubes. Subsurface soil samples were collected and submitted for laboratory analysis during the intrusive investigation. Samples were collected from the base of the excavated trench and from the trench side walls and were analyzed for select chemical agents and ABP (Parsons, 2006).

3.2.2.5. The intrusive investigations at the former Harvard TR resulted in the discovery of CAIS-related items at two anomaly locations. One anomaly location contained a lid and a bolt from a pig. The second anomaly location contained four empty pigs, packing material, 34 empty 3.5-ounce glass bottles, and broken glass from K941 CAIS. Figures 3.1, 3.2, and 3.3 show items found during the Harvard TR investigation. Other items recovered during the investigation included two M69, fuzed incendiary bomblets wedged into the exploded casing of an M47 100-lb bomb, an empty burster

tube, M69 counterweights, rolls of barbed wire, rebar, sheet metal, tractor parts, and metal spikes (Parsons, 2006).

Figure 3.1: One of four CAIS "pigs" found during the Harvard TR investigation

Figure 3.2: CAIS packing materials located during the Harvard TR investigation

Figure 3.3: 3.5-ounce bottles from K941 CAIS located during the Harvard TR investigation

3.2.2.6. Nine soil samples were collected from locations where potential CWM was excavated during the intrusive investigation. Soil samples were collected from underneath CAIS bottles and CAIS shipping containers; soil inside of CAIS shipping containers; and composites of soil from the area of the CAIS discovery. Headspace analysis for chemical agents was performed by ECBC personnel on each soil sample collected. Since the soil samples submitted for headspace analysis were non-detect for chemical agents, the samples were shipped to the ECBC laboratory at the Edgewood Arsenal in Aberdeen Proving Ground, Maryland and analyzed for chemical agents and ABPs. All of the soil samples submitted for analysis were non-detect for chemical agents and ABPs (Parsons, 2006).

3.2.2.7. Five aqueous samples were also collected during the site investigation. Two samples were collected from an irrigation pond located at the northeastern end of the site; one was collected from the irrigation well located down gradient from the site; one was collected from the landowner's residential well; and a composite aqueous sample was collected from Investigation-Derived Waste (IDW) water. The aqueous samples collected from the irrigation pond, irrigation well, and residential well were all non-detect for chemical agents and ABP. The aqueous sample collected from the IDW contained elevated levels of chloroform with regards to waste disposal (Parsons, 2006). The elevated chloroform levels were attributed to being a byproduct of the bleach used in decontamination solutions. The IDW water was containerized and transported off-site for disposal by a disposal contractor.

3.2.2.8. The results of the ECBC air monitoring conducted at the excavations were non-detect for chemical agents throughout the operations at the former Harvard TR (Parsons, 2006).

3.2.2.9. In the case of Harvard Target Range, the CAIS bottles were found only because they were buried adjacent to steel pigs. The possibility remains that additional bottles are located at the site but cannot be found due to inability to detect buried glass.

3.2.3 Santa Rosa Army Airfield, California

3.2.3.1. Santa Rosa AAF operated from 1942 to 1945 to train fighter pilots and ground crews. Training included identification of chemical agents using CAIS. Records indicate that CAIS were probably stored at a magazine or small storage building at the magazine area. Outdoor agent identification training with the CAIS was conducted near the gas chamber building adjacent to the magazine area (Parsons, 2005b). On September 5, 1945, the base Chemical Warfare Section prepared a 30-day deactivation plan to dispose of chemical training materials. All serviceable items were to be packed and shipped away; unserviceable items were to be turned into salvage (Parsons, 2005b). The chemical training operations were completely inactivated by December 15, 1945. In March of 1948, the Ordnance Department certified that the Santa Rosa AAF contained no explosives or hazardous materials (Parsons, 2005b).

3.2.3.2. In November 1982, workers digging a utility trench in the former magazine area accidentally encountered and broke a CAIS ampoule from a K951/K952 set containing a 5% Lewisite solution; fourteen workers incurred minor injuries from breathing the vapor cloud (Parsons, 2005b). The initial Army investigation found glass shards equivalent to approximately 50 additional ampoules spread over an area 15 feet across. The shards are interpreted to be from a former demonstration area where K951 CAIS were detonated (Parsons, 2005b). In 1983, the cleanup continued by excavating a pit that was 90 feet by 35 feet by 6 feet deep and sifting the soils from the pit. Empty bottles (K941) and more broken and empty ampoules (K951/K952) were found confined to a small 4-foot-by-4-foot area no deeper than 2½ feet. No liquid chemical agent or residual contamination was found during the operation; air monitoring did not detect any chemical agent (Parsons, 2005b). In 1985 at a nearby location, a worker was injured when the backhoe he was using to excavate a foundation broke another ampoule and released a white cloud. The cleanup found 10 intact bottles, 5 of which were filled with mustard (K941), and 1 broken bottle (Parsons, 2005b).

3.2.3.3. Based on the number and proximity of glass shards, the ampoule of Lewisite broken in 1982 was likely overlooked during training and buried at the site where demonstrations using the K951 CAIS were conducted. The bottles (K941) and other ampoules are interpreted to have been buried at two separate locations as a means of disposal.

3.2.4 Jackson Fairgrounds, Mississippi

3.2.4.1. Between 1927 and 1929, Hinds County officials designed and built an armory on the Jackson Fairgrounds site. Though built and owned by Hinds County, County officials made the structure available to the Mississippi National Guard. While controlled by the National Guard, members of the 31st Infantry Division (Dixie Division) were assigned to the Armory. During their assignment at the location, the Dixie Division was federalized into service in both World War II and the Korean Conflict. It is believed that local Army installations may have loaned training aids for chemical agent recognition and demonstration purposes to the Mississippi National Guard troops assigned to the Jackson Armory (Parsons, 2005c). Historical documents showed that National Guard units used CWM in training scenarios at annual summer camps and in conjunction with civil defense organizations such as local police and fire departments. Although documents showed that the Mississippi National Guard received shipments from the Chemical Warfare Service, the records were not usually specific. The records listed "chemical ammunition" and the only specific items found on the documentation were chloroacetophenone (CN, a tearing agent) candles (Parsons, 2005c).

3.2.4.2. In April 1995, glass ampoules from CAIS were found at the Jackson Fairgrounds while excavating a utility trench (Parsons, 2005c). The CAIS were found where the utility trench crossed an abandoned baptismal font belonging to what used to be Fairview Baptist Church. The Fairview Baptist Church was formerly located across the street from the National Guard Armory on the Jackson Fairground's site. The origin of the CAIS found on the Jackson Fairgrounds site is uncertain, but the items may have come from one of the nearby military facilities, such as Jackson Army Airfield, Camp Shelby, or Jackson Armory.

3.2.4.3. Local and State emergency officials, in conjunction with the U.S. Army Technical Escort Unit (TEU) and the Corps of Engineers, responded to the CAIS discovery incident and recovered what is believed to be all the CWM from the location (Parsons, 2005c). During the excavation of the utility trench, a second site was inadvertently created by relocation of the excavated soil. The spoils from the utility trench also contained CAIS items and had to be inspected before completion of the emergency response operation.

3.2.4.4. On May 19th, 1995, the Mississippi State Department of Environmental Quality declared the remediation of the site complete (Parsons, 2005c). The CAIS found at the location consisted of 268 ampoules (K951/K952) along with other chemical training items used in troop training demonstrations. The ampoules contained mustard, Lewisite, chloropicrin, and phosgene. In addition, the eighteen bottles uncovered during the trenching operation contained activated charcoal impregnated with Lewisite, chloropicrin, mustard, chloroacetophenone, Adamsite, and triphosgene without charcoal (Parsons, 2005c). These would have been from K955 or Navy X sets.

3.2.4.5. In the case of the Jackson Fairgrounds site, the CAIS bottles were found as a result of trenching operations for the installation of utilities. It is not known how the

CAIS items ended up on the Fairground site. It is believed that the items were either buried after a 1937 fire at the armory or deposited there by soldiers from nearby Camp Shelby. Although no other disposal areas have been identified at the Jackson Fairgrounds site, the possibility remains that additional CAIS may be present at the site.

3.2.5 5th Field Marine Supply Depot, Guam

3.2.5.1. The 5th Field Marine Supply Depot was established in January 1944 after the recapture of the island of Guam from the Japanese and was a component part of the Supply Service Fleet Marine Forces, Pacific. The depot was officially closed in December 1949 (Parsons, 2005d).

3.2.5.2. In July 1999, a resident located within the boundary of the former 5th Field Marine Supply Depot discovered CAIS shipping containers (pigs) buried on his site while excavating a waterline (Parsons, 2005d). On July 24, 1999, under an emergency removal action, sixteen pigs were overpacked by the U.S. Army Technical Escort Unit (TEU) and removed from the site. The pigs were assessed and determined to contain K951/952 CAIS. The CAIS pigs were sent to Johnston Atoll for destruction.

3.2.5.3. The USAESCH performed a geophysical survey within a 300-foot radius of the initial CWM CAIS recovery pit between February and March 2000 (Parsons, 2005d). On March 1, 2000, non-pit intrusive investigations began on the site. Contractor and TEU personnel dug anomaly locations determined to fall into the non-pit category using hand-shovels and a backhoe. Non-pit investigations ceased on March 13, 2000, for re-evaluation of the work plan after personnel encountered a 5" fuzed naval round, possibly left from the battle to recapture Guam. A total of 489 anomalies were investigated during the first non-pit intrusive effort. A total of 94 of these were originally potential pit anomalies, but were investigated under depth restrictions. The second non-pit intrusive investigations were conducted beginning May 29, 2000. Contractor and TEU personnel dug the anomalies using hand-shovel and a backhoe. The second non-pit intrusive effort investigated 617 anomalies. A total of 457 of these were originally potential pit anomalies, but were investigated under revised depth restrictions and conditions outlined in Amendments to the work plan.

3.2.5.4. On March 27, 2000, potential pit intrusive investigations began at the site. Intrusive investigation was conducted at all anomalous areas with a signature equal to or greater than three CAIS pigs within a 300-foot radius of the initial discovery, as determined by the geophysical survey. TEU/Contractor personnel in modified Level D Personal Protective Equipment (PPE) performed the excavation. Modified Level D consisted of wearing coveralls, protective gloves, protective boots, and carrying an air-purifying respirator at the ready. PPE was upgraded to Level C when CAIS pigs were discovered. No leaking or opened CAIS pigs were encountered during the investigation (Parsons, 2005d).

3.2.5.5. Nineteen CAIS pigs were found during investigations of potential pits (Figure 3.4). All of the CAIS pigs were found in the first pit, were in good condition, and

showed no evidence of leaking. Each pig was containerized and transported to Andersen Air Force Base (AFB). Each shipping container was x-rayed by TEU personnel at Andersen AFB. TEU concluded that each pig contained four CAIS kits. The pigs were transported to Johnston Atoll Chemical Weapons Destruction Facility for final destruction. No CWM items were encountered during the non-pit investigations conducted at the former 5th Field Marine Supply Depot (Parsons, 2005d).

Figure 3.4: Some of the CAIS pigs recovered in Guam

3.2.5.6. In the case of the former 5th Field Marine Supply Depot, the CAIS pigs were found as a result of excavation activities for the installation of a water line. The focused investigation conducted at the site identified numerous subsurface metallic objects and subsequent excavation of nineteen CAIS pigs. No individual CAIS ampoules or bottles were associated with the buried pigs. The possibility exists that individual ampoules or bottles may be present at the site but cannot be found due to the inability to detect buried glass.

3.2.6 Lowry Bombing and Gunnery Range, Colorado

3.2.6.1. The former Lowry Bombing and Gunnery Range, formally known as Buckley Field, opened in 1942 as an Army airfield, and was part of the Army Air Corps Western Technical Training Command during World War II. In 1946, land was assigned to Lowry Air Force Base as the Lowry Bombing and Gunnery Range (LBGR).

3.2.6.2. Historical records indicate that all troops at Buckley Field received chemical warfare training. A Chemical Warfare Range and Chemical Warfare Range 2 were established at Buckley Field. Records indicate these facilities were located at Buckley Field proper and not at the bombing range portion of the facility (Parsons, 2005e). A base history for July and August 1944 stated that all chemical warfare ammunition was stored in magazines either in the corridor between Buckley Field and the Bombing and Gunnery Range or on the Buckley Field site. A 1945 inventory showed that Buckley Field had M1 detonating gas identification sets.

3.2.6.3. In 2000, subsurface clearance activities were initiated in the Jeep/Demolition (J/D) Range for conventional munitions. During these conventional munitions response activities in the J/D Range, TEU was called to respond to the LBGR five times to assess potential CWM (Parsons, 2005e). The first incident occurred in

January 2001 because of a M139, 4.5-inch diameter chemical bomblet found in a trench at the J/D Range. The M139 was designed to contain the nerve agent sarin (GB) but this bomblet was found to contain a simulant. TEU responded twice in February 2001 because of M125, 10-pound, cluster bomblets found during the J/D Range clearance of a second trench location. During March 2001, TEU was called in response to a M34, 1,000-pound cluster bomb, which held 74 M125 bomblets. Each of these instances resulted in positive field confirmation by TEU that the items were inert, simulant-filled, training items. In January 2001, one empty CAIS shipping container ("pig") was found in the second trench location (Figure 3.5). TEU was not notified of this find due to the fact that the shipping container was empty (Parsons, 2005e).

Figure 3.5: CAIS pig found at Lowry BGR

3.2.6.4. On March 20, 2002, a contractor uncovered eight bottles from a K941 CAIS and three empty, open, shipping containers from an excavation in the J/D Range. Two 3.5 ounce bottles labeled "HS," the standard letter code for sulfur-based mustard, were found (Parsons, 2005e). One bottle contained a clear liquid, and the other contained a dark residue. TEU was called to respond, but field tests could not positively identify the contents as inert. The bottles were transported to Pueblo Chemical Depot (PCD) for further testing.

3.2.6.5. Lab tests from PCD indicated that the liquid contained a sulfur-based compound. Additional testing of the liquid samples at the Rocky Mountain Arsenal indicated the presence of both sulfur mustard degradation and thermal combustion compounds. These results indicate that the bottles may have contained sulfur mustard, which was potentially destroyed by thermal treatment. The results also indicated that the solid residue was a sulfur and chlorine compound. Although this is consistent with mustard and its breakdown products, it could also be associated with a number of other compounds. The analysis of the solid residue was inconclusive as to whether the residue was mustard agent or a simulant. No mustard agent (sulfur or nitrogen) was detected in any of the samples (Parsons, 2005e).

3.2.6.6. In addition, broken ampoules from the K951/952 CAIS and broken bottles from the K955/Navy X-Sets were also recovered. These items were also removed, packaged, and transported to PCD. As a result of these findings, a CWM removal action was initiated in response to the items identified on the J/D Range during the conventional munitions response activities.

3.2.6.7. The scope of the removal action focused only on the J/D Range and included areas that had been previously identified to contain CAIS; suspect burial trenches; and anomalies providing a geophysical signature consistent with one CAIS shipping container or larger. Intrusive operations conducted from June 2003 through February 2004 investigated 256 locations for the presence of CWM. These locations included 2 targets in the previously identified CWM locations; 229 targets whose geophysical characteristics were consistent with CAIS shipping containers; and 25 targets in trench spoils clearance locations.

3.2.6.8. The investigation of the two targets in the previously identified CWM locations found fourteen intact 3.5-ounce bottles (twelve labeled "HS", two with no markings), two 30-gallon decontamination agent non-corrosive (DANC) drum lids, one shipping container flange end, an empty booster cup, broken glass, charred wood, and various metal scrap (Parsons, 2005e). TEU stated that none of the bottles contained suspect liquid, specifically chemical agent or ABP. The bottles recovered during the removal action indicate the CAIS was a K941.

3.2.6.9. Possible CWM related items recovered from the investigation of the 229 geophysical anomalies consisted of one M125 bomb scrap, one Livens projector, and fifteen CAIS components (Parsons, 2005e). The CAIS components consisted of remnants of K955 cans used for packaging the CAIS inside the shipping container, and the flange ends of shipping containers. The CAIS components were not recovered with any glassware and there were no indications of stained soil. MINICAMS and DAAMS did not detect agent during air monitoring. Soil samples collected from inside and immediately below the Livens Projector were non-detect for chemical agent and ABP.

3.2.6.10. CAIS shipping containers, glassware, and M125 bomb scrap were previously recovered from the two munitions burial trenches investigated during conventional munitions response activities. As part of the removal action, select locations within the spoils piles were investigated for additional CWM or CWM related items. Four pieces of M125 scrap were recovered during the investigation of the spoils piles. Soil samples were collected from the bottom and sidewalls of each trench and analyzed for chemical agent and ABP. The results of the soil samples were non-detect for chemical agent and ABP. No indications of chemical agent were detected (Parsons, 2005e).

3.2.6.11. In September 2005, a loose K951 ampoule was found at Lowry BGR at the J/D Range in an area with a lot of broken glass, presumably from CAIS ampoules. The ampoule was found as part of the routine ordnance clearance operation that was

continuing at Lowry BGR. There were no injuries. The ampoule was slightly fractured but still contained an unknown liquid. TEU responded and assessed the ampoule finding that the liquid gave a positive reading for mustard using M8 detection paper. The liquid in the ampoule was destroyed by being placed in a bucket of decontamination solution (Defense Ammunition Center, 2005).

3.2.6.12. The initial discovery of CAIS and CAIS-related items at the former LBGR resulted from a conventional munitions investigation conducted at the former installation. A CWM removal action initiated in response to these findings located additional CAIS and CAIS related items. The CAIS bottles recovered during the investigation were located due to their proximity to CAIS shipping containers and various metal scrap. As demonstrated by the 2005 incident, it is possible that additional CAIS bottles are present at the former installation but were not located due to the inability to detect buried glass.

3.2.7 Coffeyville Army Airfield, Kansas

3.2.7.1. A Chemical Service Company was organized at Coffeyville in July 1942 to administer chemical warfare training to Coffeyville AAF personnel. The Company was inactivated in October 1942 and members became the chemical section of an Air Base Squadron organizing a chemical warfare school in 1943. The school facilities included a toxic gas yard, a pyrotechnics storage building, a gas instruction building, and a chemical warfare warehouse. Training is known to have included the use of mustard, chlorine gas, white phosphorus grenades, and smoke pots (Parsons, 2005f).

3.2.7.2. In April 2003, a collection of CAIS ampoules and other military items were discovered in a barn just east of Coffeyville, Kansas (Parsons, 2005f). The former owner (deceased) was a former Army Chemical Corps soldier. The former owner was a Chemical Specialist from 1941 to 1945 and was trained in chemical agents, conducted classes and worked in chemical supply and inspection. The CAIS ampoules were in cardboard tubes labeled HS (mustard), CG (phosgene), and PS (chloropicrin) (Figure 3.6). Based on the types of agent, packaging, and labels, the CAIS was type K951/K952. The ampoules were removed from the barn and destroyed by TEU. Review of the former owner's military records indicated that he was never stationed at Coffeyville AAF, so the CAIS ampoules likely came from another location.

Figure 3.6: Box with CAIS ampoules in cardboard tubes (marked HS)

3.2.7.3. The CAIS items recovered in Coffeyville, Kansas were not discovered as a result of excavation or investigation activities but were likely kept by the former Army Chemical Corps soldier as a souvenir. The recovery of CAIS at Coffeyville reflects the general perception that CAIS were expendable training materials and consequently they were not closely controlled or documented.

3.2.8 Raritan Arsenal

3.2.8.1. The Raritan Arsenal operations included receiving, storing, shipping, transferring, re-storage, and re-packing of ammunition. The Ordnance Specialist School was located at Raritan Arsenal from 1919 until 1941. During this time, a disposal area designated Area 5 was used to dispose of leaking munitions and containers that were transported to Raritan Arsenal by barge. In 1951, the Provisional Unit Training Center was established at Raritan Arsenal to train and activate Explosive Ordnance Disposal units. During 1951 and 1952, ordnance and chemical agents were routinely destroyed by burial or burning in chambers or pits. The procedure for disposal of CWM included digging a pit 5 feet wide by 5 feet long by 5 feet deep and pouring liquid mustard out of the munition or container into a decontaminating solution in the pit. The empty containers were then placed in the pit and the pit was filled with dirt and a sign was installed marking the type of agent and the date of burial.

3.2.8.2. Raritan Arsenal is different from the sites presented above in that burial areas were known and CAIS were not discovered by accident. Investigation activities conducted at Raritan Arsenal have removed several tons of ordnance, bulk explosives, and chemical agent contaminated materials. During an investigation in 1996, 192 drums of mustard-contaminated soil and debris, hydrazine, and grenades were transported off-site for incineration. Approximately 30 cubic yards of arsenic-contaminated soils (Lewisite residual) was disposed of in a local landfill. In addition, hundreds of CAIS ampoules, broken and intact, were recovered from the site. Raritan Arsenal is included in

this discussion because even though hundreds of CAIS ampoules, many of which were broken, were recovered from the burial pits, only low level mustard contamination was detected in the groundwater. Due to the disposal of other mustard containing items in the area, it is not known if the low level mustard contamination to groundwater was a result of the CAIS disposal alone. Also, the inability to detect buried glass with current geophysical technology makes it possible that additional CAIS remain at Raritan Arsenal. The collection of environmental samples is not likely to detect contamination unless samples are collected in close proximity to a burial pit containing a large number of CAIS ampoules or a burial pit where large amounts of bulk chemical agent was disposed.

3.3 CAIS INVESTIGATION METHODOLOGY

3.3.1 Introduction

This section presents the various detection methods that may be used to locate buried CAIS. The methods can be grouped into those methods that can directly detect CAIS and methods that can indirectly detect CAIS through locating ground scars or measuring released chemicals in air, soil, or groundwater.

3.3.2 Direct Detection Methods

3.3.2.1 In order for direct detection methods to be effective, a suspected burial location must be known in order to reduce the size of the area studied rather than investigate entire installations encompassing hundreds to thousands of acres. Even knowing where chemical warfare training took place or locations of storage facilities is insufficient to narrow the focus given the wide variety of locations where CAIS have been found at FUDS.

3.3.2.2 Direct detection methods consist primarily of using geophysical instruments such as metal detectors, magnetometers, and ground penetrating radar. Instruments such as metal detectors, magnetometers and electromagnetic instruments can only detect metallic objects. CAIS in shipping containers and drums can usually be detected using these instruments if data are collected on a tight spacing, if the containers are relatively shallow (upper 5 to 8 feet), and if there is an absence of interference from surface culture and buried utilities. Detection of cardboard tubes with metal ends or metal cans that contain ampoules or bottles may or may not be detected depending again on survey spacing, depth, condition of the metal and background noise levels. For bottles and ampoules not in shipping containers or without metallic packaging, only proximity to metallic items will allow detection by these metal detecting instruments. Glass containers located away from metal will not be detected.

3.3.2.3 Ground penetrating radar (GPR) is a direct detection method with the potential to detect glass containers. The problem with this method is the inability to distinguish glass from rocks. In addition, the limitations of decreasing resolution with depth and problems associated with surface clutter, soil saturation, and conductive soils would limit this method's application to ideal circumstances such as small areas on parking lots and on athletic fields. GPR has some capability to identify burial trenches by

mapping discontinuities in soil layering. This technique, in conjunction with metal detection methods, may be useful to select targets for excavation at areas where burial sites are suspected. Although less effective and less efficient than metal detection methods, GPR could be used to locate steel pigs and drums used to store CAIS.

3.3.2.4 Excavation, as a means of exploration for CAIS burial sites, is impractical for all but the smallest areas of investigation. This method requires careful examination of soil removed from an excavation to detect the small glass CAIS bottles and ampoules. Excavation has been used to investigate geophysical anomalies identified by other direct detection methods; however, as shown by the Santa Rosa AAF case history, the successful use of excavation does not mean that CAIS do not remain buried elsewhere at the site.

3.3.3 Indirect Detection Methods

3.3.3.1 Indirect detection methods primarily use remote sensing such as aerial photographs and satellite images to find indications of burial sites where CAIS may remain. Historical aerial photographs, if taken at the right time, might show burial trenches or ground scars from excavation activities. Such information can be used to reduce an area of interest from a large area to a smaller area that might be practical to investigate using direct detection methods. The limitation is that the photographic information for the correct period is frequently not available and, if available, the photographic information must be used with historical documentation of suspected burials. Otherwise, investigation of ground scars could lead to wasted effort excavating areas that had scars possibly due to vehicle traffic, logging operations, construction, or practice foxholes.

3.3.3.2 Another possible indirect detection method is to collect environmental samples from soils and groundwater and analyze them for chemical agents and agent breakdown products. This method is only effective once CAIS have been identified or if a disposal site has been confirmed. The analysis of soils collected from directly beneath CAIS ampoules and bottles found in investigations have been non-detect or at very low levels for chemical agent and ABP. Similarly, groundwater and surface water samples have not provided detections. Only at Raritan Arsenal, where hundreds of CAIS were buried in pits and many were found broken, was mustard detected at low levels in groundwater. As an example, a K951 CAIS contains 12 ampoules each of diluted H and L. These persistent agents total 24 mL of H and 24 mL of L for the entire set. Because of the small quantities of chemical agents and industrial chemicals in the CAIS, analysis of environmental samples has not been a productive means of investigation at sites, as demonstrated by the sampling and analysis conducted at the 5th Field Marine Supply Depot, Lowry Bombing and Gunnery Range, and Harvard Target Range.

3.4 LIMITATIONS OF EXPLORATORY TECHNOLOGY

3.4.1 The CWM Scoping and Security Study identified a group of suspect CWM sites where the only potential CWM concern remaining at the site was CAIS. Since

historical records are incomplete and do not include information on the final disposition of the CAIS at these sites, there is a remote chance that buried CAIS may remain in portions of the property. Further investigation of these sites is considered technically unfeasible due to the limitations of available exploratory technology. CAIS were normally packaged in cardboard (sometimes with thin metal lids and bottoms) and stored in small steel cans, steel shipping containers (pigs), wooden boxes, or plastic cases. The steel drums and pigs represent good metallic targets readily detected by geophysical equipment; however, the wooden boxes, plastic cases, and loose bottles and ampoules contain little or no metal and are not detected by current geophysical technology. This analysis has been borne out by the ready detection of metal CAIS related items at several sites; 5th Field Marine Supply Depot, Guam; Lowry Bombing and Gunnery Range/Buckley Field, Colorado; and Harvard Target Range, Nebraska.

3.4.2 No current geophysical technology is effective in locating individual glass CAIS bottles or ampoules. At sites where CAIS are suspected, efforts can be made to narrow the search areas using historical information, eyewitness accounts, and aerial photographs. However; the locations of the wooden boxes, plastic cases, loose bottles, and ampoules can only be determined through the detection of associated secondary targets such as metal associated with the items (steel pigs, cans, metal caps, hinges, etc.). Unfortunately, the secondary targets are not always present.

SECTION 4
NATURE AND EXTENT OF CONTAMINATION AT CAIS SITES

4.1 INTRODUCTION

The primary issue with CAIS is that for any site where they were used or stored, some may still remain. The nature and extent of CAIS contamination remaining at such sites is largely unknown. This statement is based on the following factors:

1. Since CAIS were regarded as expendable training materials, their use was not closely documented. Documentation regarding the use or disposal of CAIS at many sites is incomplete or unavailable.
2. Although some training and storage areas might be identified, evidence from several sites shows that the locations of burials can occur nearly anywhere on an installation.
3. Loose CAIS bottles and ampoules in the subsurface are undetectable using currently available technology. Loose bottles and ampoules found to date were located only because they were in proximity to large metallic objects such as CAIS pigs or steel drums, or they were encountered accidentally.

4.2 TYPES OF FACILITIES

All of the sites under consideration for this study either stored CAIS or used CAIS for training. A review of the sites evaluated by the CWM Scoping and Security Study indicates that most sites fall into the following categories:

- Arsenals and depots.
- Camps and forts.
- Airfields.

Sites of the same category are similar in the way that CAIS were used or stored at those sites. General descriptions are provided below in regard to where CAIS were used and stored for these facility categories.

4.2.1 Arsenals and Depots

Arsenals are distinguished from depots by being locations where munitions and equipment were developed. Over the years and especially during wartime, both types of facilities were used for storage of equipment and munitions. There is little information on how CAIS were stored; however, it is presumed that both explosives storage magazines and warehouses would have been used for storage although CAIS would

likely have been segregated from munitions and other equipment. A few arsenals and depots converted outlying areas to basic military training facilities during wartime. The locations of training would mostly have been outside the danger zones surrounding magazines and igloos where explosive munitions were stored. Training at these facilities would have included protection against chemical agents, agent identification, and handling and decontamination of leaking chemical munitions. All three main types of CAIS may have been used for training at these facilities. Unless training for units or replacement troops was also being conducted at the facility, the numbers of troops trained would have been rather low and limited to the depot operations troops. Disposal of CAIS could have occurred at any isolated area of these facilities.

4.2.2 Camps and Forts

Army camps and forts were used to train and house military personnel. Camps are typically temporary facilities established in wartime. Forts are more permanent facilities. Chemical warfare training was conducted in classrooms, in the Chemical Warfare Building (also known as a Gas Instruction Building or Gas Chamber), and at outdoor demonstration areas. The gas chambers and outdoor demonstration areas were sometimes located near each other, but at some facilities they were separated. Documentation on the location of CAIS storage is unavailable for many installations; however, there is evidence at some facilities that CAIS were stored in small buildings at the ordnance (or magazine) area or in small buildings at the chemical warfare training area. Disposal of CAIS could have occurred at any isolated area of these facilities.

4.2.3 Airfields

While a few military airfields existed prior to World War II, hundreds of airfields were constructed in the years just before and during World War II. Most of the uniformed personnel at military airfields underwent training in protection from chemical agents and agent identification. These personnel were usually trained using CAIS “sniff sets” and detonating sets. A limited group, typically consisting of depot and ordnance personnel, was also trained in decontamination procedures. These troops may have used detonating sets or sets with undiluted mustard (K941). Training with “sniff sets” would have taken place inside classrooms. The training with detonating sets and decontamination training occurred in a designated area at least a few hundred feet from other facilities. CAIS were stored at the Chemical Warfare Warehouse (sometimes called a Storage Building) or segregated from munitions in the ordnance area. A Chemical Warfare Building (Gas Instruction Building or Gas Chamber) was used for training in gas mask proficiency. Army airfields and Naval air stations had similar facilities for chemical warfare training. Airfields are the most numerous facility type in which CAIS was the only type of CWM used. Disposal of CAIS could have occurred at any isolated area of these facilities.

4.2.4 Other Sites

There are a few other sites that potentially have CAIS remaining. These include other facilities where chemical warfare training occurred such as naval bases, and sites

where chemical warfare agent testing was conducted. Although in this second group, CAIS would not have been the only type of CWM used, so they would be excluded from this study. There are also instances where CAIS were disposed of by burial on non-military sites.

4.3 DOCUMENTATION

4.3.1 As stated earlier, documentation of use and disposal of CAIS is largely unavailable. Inventories of chemical warfare training supplies were made at Army Air Forces facilities at the end of February 1945. One entry on the inventory was "Set, gas, identification, detonating, M1," which represents the K951 sets. The forms provided spaces for the number authorized, currently on hand, and currently loaned out on memo receipt (interpreted to mean that these were in use for training at the time of the inventory). These inventories provide a good snapshot of the detonating CAIS (K951) on hand or in use toward the end of World War II. Although some facilities continued with chemical warfare training beyond February 1945, training had ceased at most facilities. Records were found for 243 Army Air Forces facilities. The records show that one third (33%) of the facilities had no K951 CAIS on hand or in use in February 1945. About 35% had 2 or less (fractions of sets were reported in some instances) and about 16% of the sites had between 2 and 5 K951 CAIS on hand or in use. Sites with more than 5 and up to 10 CAIS were 8% of the total. Only 10% of the facilities had more than 10 and these sites may have been regional distribution centers for other airfields. The number authorized was typically only reported if CAIS were on hand or in use. Records for other time periods or for other types of CAIS could not be found.

4.3.2 The important conclusion is that for most facilities only small numbers of CAIS were used or kept on hand. However, records are unavailable for many facilities and for those facilities where records are available; typically they are only from the early 1945 inventory.

4.4 SUMMARY

4.4.1. Potential sources of contamination consist of unopened, intact CAIS ampoules or bottles; partially filled intact CAIS ampoules or bottles; and intact empty CAIS ampoules or bottles. These items, if present, are likely to be buried beneath the ground surface but, due to the nature of some of the chemical warfare training activities, some items could be present on the ground surface. A second type of potential source of chemical agent contamination consists of CAIS chemicals released to the environment during chemical warfare training with CAIS. This would have occurred at outdoor demonstration and training areas where detonation sets and decontamination training were conducted and also potentially at disposal sites where the contents of CAIS were dumped and incompletely destroyed.

4.4.2. Analyses of soils collected from directly beneath CAIS ampoules and bottles found in investigations have been non-detect (Santa Rosa AAF and Harvard Target Range, for example) or at very low levels (Lowry Bombing and Gunnery Range) for

chemical agent and agent breakdown products. Similarly, groundwater and surface water samples have not provided detections. Only at Raritan Arsenal, where hundreds of CAIS were buried in pits, was mustard detected at low levels in groundwater. As an example, a K951 CAIS contains 12 ampoules each of diluted H and L. These persistent agents total 24 mL of H and 24 mL of L for the entire set. Because of the small quantities of chemical agents and industrial chemicals in the CAIS, analysis of environmental samples has not been productive as a means of investigation at sites, as demonstrated by the sampling conducted at the 5th Field Marine Supply Depot, Lowry Bombing and Gunnery Range, and Harvard Target Range.

4.4.3 In summary, the nature and extent of contamination from CAIS chemicals is unknown. Based on general information and incomplete records, estimates of the typical locations where training was conducted and the approximate numbers of CAIS used in training can be made. However, disposal locations can be outside of the known or suspected training locations at a given facility. Also, many facilities had small numbers of CAIS on hand toward the end of World War II but these remaining CAIS may have been used, shipped offsite or destroyed onsite. Also, records are not available for most types of CAIS and for time periods other than World War II.

SECTION 5
CONTAMINANT FATE AND TRANSPORT

5.1 INTRODUCTION

Since records regarding the shipment and use of CAIS at installations are incomplete, the potential exists for CAIS intended for use in training to remain at the site. CAIS chemicals may remain inside intact bottles and ampoules or there is the potential that the chemicals were released to the environment during training or disposal activities. An understanding of the fate of the various CAIS chemicals released to the environment is important to determining the risk posed by those chemicals to human health and the environment. The following paragraphs discuss the potential routes of migration, the persistence of the various CAIS constituents, and the contaminant migration. The primary risk posed by CAIS is not exposure to contaminated media or from the migration of chemicals through environmental media, but rather from human receptor contact with CAIS containers resulting in acute exposure.

5.2 POTENTIAL ROUTES OF MIGRATION

5.2.1 Ampoules or bottles from CAIS could have been disposed of at or near the CWM training areas or various locations within the former site boundary. These CAIS items could consist of unopened intact, crushed, partially filled, or empty ampoules or bottles. CAIS chemicals may also exist in the soil in a polymerized form as a result of chemical warfare training or from crushed or damaged ampoules. The potential routes of migration consist of the air, soil, surface water, ground water, and through the biota.

5.2.2 **Air -** Because of the relatively small quantities of chemicals considered to potentially remain, migration through the air would only be significant for the immediate vicinity following an acute release of chemicals from a bottle or ampoule.

5.2.3 **Soil –** Based on the physical properties in which they exhibit, CAIS chemicals could migrate through the soil. If released into the soil, some of the chemicals and their breakdown products may potentially leach through the soil; however, the small quantities of chemicals would only be significant in the vicinity of the release.

5.2.4 **Surface Water –** CAIS chemicals may migrate through surface water in instances where CAIS have been disposed of in lakes, ponds, or rivers, or when chemicals have leached from the soil into surface water runoff. The small quantities of chemicals from an acute release would be rapidly diluted to non-hazardous levels.

5.2.5 **Groundwater** – Some CAIS chemicals and breakdown products may leach from the soil into the groundwater. The small quantities of chemicals from an acute release would be rapidly diluted to non-hazardous levels.

5.2.6 **Biota** – There is a potential that some of the CAIS chemicals or breakdown products may become concentrated in organisms. Again, the small quantities released would only impact a small area.

5.3 CONTAMINANT PERSISTENCE

The chemical constituents of CAIS consist of mustard (H, HS, or HD), Lewisite (L or M-1), nitrogen mustards (HN-1 and HN-3), chloropicrin (PS), phosgene (CG), cyanogen chloride (CK), triphosgene, chloroacetophenone (CN), Adamsite (DM), the nerve agent simulant diethyl malonate, and chloroform. The persistence of these chemicals in various media is described in the following paragraphs. Table 5.1 shows the physical properties of CAIS chemicals. Table 5.2 contains toxicity parameters. The persistence of each chemical is summarized in Tables 5.3 through 5.12.

5.3.1 Sulfur Mustard (H, HS, HD)

5.3.1.1 Mustard (H, HS, or HD) is a strong blister agent, or vesicant. First employed by the Germans in World War I in July 1917, it is commonly referred to as "mustard gas." Mustard, referred to as sulfur mustard or Levinstein mustard after the manufacturing process, is usually a yellow to brown oily liquid (colorless when pure) with a slight garlic or mustard odor. The purity of mustard varied having as much as 30% impurities. These earlier varieties were designated H or HS. The distilled mustard (HD) produced after the start of World War II was much purer than the mustard produced with the earlier Levinstein process (designated H or HS). A blister agent, the primary active ingredient is bis(2-chloroethyl)sulfide, although impure mustard includes other compounds with similar properties. Weapons grade mustard can contain stabilizers, starting materials or byproducts formed during manufacturing, and products formed from slow reactions over time (Munro, *et al.*, 1999). The mustards H, HS, and HD in CAIS were packaged in undiluted form, as a 5 percent solution, or absorbed in charcoal. Mustard is the most prevalent chemical agent found in CAIS being found in all types of sets.

5.3.1.2 Mustard is extremely toxic to humans whether contact is through inhalation, ingestion, injection, or absorption through the skin. Mustard exists in both the liquid and gaseous phases. The human sense of smell will not always detect the presence of mustard because it can be odorless, smell sweet, or have a strong garlic and mustard odor. Pure mustard has a freezing point of about 57°F (14°C), which means that in winter mustard may remain undetected until the temperature rises above its freezing point. Impurities and solvents, such as the chloroform used in K951/K952 and K953/K954 CAIS, tend to lower the freezing point.

5.3.1.3 Sulfur mustard is a vesicant or blister agent that possesses strong alkylating properties and consequently demonstrates systemic toxicity in addition to its effect on skin, eyes, and respiratory tract. The first symptoms of mustard poisoning usually appear within four to six hours. The higher the concentration of mustard at exposure, the shorter the interval time between the exposure to the agent and the first symptoms. Mustard is considered a known human carcinogen. Some mustard breakdown products are toxic and, in some cases, have vesicant action. These products include mustard- and hemi-mustard-thiodiglycol aggregates, mustard sulfone, and divinyl sulfone. Other products, such as thiodiglycol (TDG), exhibit low to slight toxicity and do not retain vesicant properties. TDG is relatively nontoxic upon acute exposure; however, TDG is an occupational eye, skin, and mucous membrane irritant (Munro, et al., 1999).

5.3.1.4 Two of the persistent thermal and hydrolysis degradation products of mustard, 1,4-dithiane and 1,4-oxathiane, have been detected in groundwater and in mustard that has been in storage. The limited acute toxicity data for 1,4-dithiane suggest low acute lethality. The acute toxicity of 1,4-oxathiane is also relatively low. The substance is a mild skin irritant and moderate eye irritant in mammals (Munro, *et al.*, 1999).

5.3.1.5 Hydrolysis is the predominant mechanism of environmental degradation of mustard. Hydrolysis is the decomposition of a chemical compound by reaction with water. Because of the low aqueous solubility of mustard, the rate of hydrolysis is determined by the amount of surface area exposed to the solvent (water), which is a function of particle size and turbulence. Pure mustard spilled into seawater would probably sink, remaining on the bottom where it would slowly dissolve. Some agent might form a surface film on the water where it would be removed within a few days by hydrolysis and volatilization (Munro, *et al*., 1999). Experience has demonstrated that mustard can remain stable underwater for years at low temperatures if there is little turbulence or mixing. Hydrolysis rates have been found to vary significantly, increasing in the presence of solvents (such as chloroform), with higher temperatures, and with greater turbulence. Hydrolysis is much faster in freshwater than seawater (MacNaughton *et al.*, 1994). In contrast to seawater, mustard is not transported by groundwater because of its low solubility and rapid hydrolysis when dissolved. While mustard is not normally found in groundwater, TDG may be found and is miscible with water and may be found in groundwater or surface water (Munro, *et al*., 1999).

5.3.1.6 The primary breakdown products of mustard are 1,4-dithiane, 1,4-oxathiane, and thiodyglycol (TDG). A number of the short-lived hydrolysis products of mustard can still produce toxic effects. Dechlorination of sulfone produces divinyl sulfone, which causes eye irritation and tearing, and is highly toxic if injected. TDG appears to produce signs of toxicity similar to glycols. Breakdown products (sulfone and sulfone oxidation products) of TDG are considered non-toxic but vesicant. (MacNaughton *et al.*, 1994).

Table 5.1
Physical Properties of CAIS Chemicals

Chemical Abreviation	Common Name	Chemical Name	Physical State	Odor	Boiling Point (°C)	Melting/Freezing Point (°C)	Liquid/Solid Density (g/mL)	Vapor Density (relative to Air)	Volatility (mg/m^3)	Vapor Pressure (torr)	Reference
HD	Sulfur Mustard	Bis (2-chloroethyl) sulfide	Pale yellow to dark brown oily liquid; colorless when pure	Garlic- or horseradish-like	218	14.45 (FP)	1.2685 (25 °C)	5.5	9.06×10^{2} (25 °C)	1.06×10^{-1} (25 °C)	(1)
HN-1	Nitrogen Mustard	2,2'-Dichlorotrithylamine	Dark, Oily liquid; colorless when pure	Faint, fishy or soapy	192	-34.2 (MP)	1.086 (25 °C)	5.9	2.23×10^{3} (25 °C)	2.44×10^{-1} (25 °C)	(1)
HN-3	Nitrogen Mustard-3	2,2', 2"=Trichlorotriethylamine	Dark, Oily liquid; colorless when pure	Geranium-like; no odor when pure	257	-3.74 (MP)	1.2352 (25 °C)	7.1	1.2×10^{2} (25 °C)	1.1×10^{-2} (25 °C)	(1)
L	Lewisite	Dichloro(2-chlorovinyl)arsine	Brown liquid, colorless when pure	Geranium-like; no odor when pure	196	-44.7 to -1.8 (FP)	1.8793 (25 °C)	7.1	3.86×10^{3} (25 °C)	3.46×10^{1} (25 °C)	(1)
CG	Phosgene	Carbonyl chloride	Colorless gas, readily liquified	Musty hay, rotting fruit	7.8	-128 (MP)	1.360 (25 °C)	3.4	7.46×10^{6} (25 °C)	1.4×10^{3} (25 °C)	(1)
CK	Cyanogen chloride	Cyanogen chloride	Colorless gas	lacrimatory and irritating	12.8	-6.9 (FP)	1.202 (10 °C)	2.1	2.62×10^{8} (12.8 °C)	7.60×10^{2} (12.8 °C)	(1)
PS	Chloropicrin	Trichloronitromethane	Colorless, oily liquid	stinging and pungent	112	-69 (FP)	1.66	5.6	1.65×10^{5} (20 °C)	18.3 (20 °C)	(2)
CN	Tear Gas	2-Chloracetophenone	Colorless to gray crystalline solid	Sharp, irritating	244 (472 F)	57 (MP)	1.3	5.3	NA	0.005 (20 °C)	(1)
DM	Adamsite	10-Chloro-5,10-dihydrophenarazine	Light yellow to green crystalline solid	No pronounced odor, iritating	410	195 (MP)	1.648 (20 °C)	9.6	negligible at ambient	negligible at ambient	(1)
Diethyl Malonate (GA-simulant)		Eythl methane dicarboxylate	Colorless liquid	Sweet, green apple, fruity	199-200	-51- -50 (MP)	NA	NA	NA	NA	(3)
Triphosgene		Bis(trichloromethyl)carbonate	White crystalline solid	NA	203-206	77-81 (MP)	1.6 (25 °C)	NA	NA	7.57×10^{2} (206 °C)	(4)
Chloroform	Chloroform	Trichloromethane	Clear, colorless liquid	Ethereal	62	-63.5 (MP)	NA	4.1	NA	1.60×10^{2} (21 °C)	(5)

References
(1) Army Field Manual 3-11.9, Potential Military Chemical/Biological Agents and Compounds, January 2005.
(2) Army Field Manual 3-9, Potential Military Chemical/Biological Agents and Compounds, Headquarters Department of the Army, 12 December 1990.
(3) Material Safety Data Sheet for Diethyl Malonate, The Good Sents Company (www.the goodsentscompany.com)
(4) Material Safety Data Sheet for Triphosgene, Chemeper.com (www/chemexper.com)
(5) Material Safety data Sheet for Chloroform. Mallenkroft Baker, Inc. (http://www.jtbaker.com)

Table 5.2
Toxic Properties of CAIS Chemicals

Designation/Name		Median Lethal Dose (liquid) LD_{50}		Median Lethal Dose (vapor or aerosol) LCt_{50}				Median Incapacitating Dose (Vapor or Aerosol) ICt_{50}						Airborne Exposure Limits
				Respiratory/Ocular (air)		Percutaneous (skin)		Respiratory (air)		Percutaneous (skin)		Eye Injury		
		(mg / 70 kg man)	Source	(mg-min/m^3)	Source	(mg-min/m^3)	Source	(mg-min/m^3)	Source	(mg-min/m3)	Source	(mg-min/m^3)	Source	(mg/m^3)
HD	Sulfur Mustard	1,400	1	1,000	1	10,000	1,2	150	2	2,000 or less	2	100 to 200	2	0.003 (STEL) 0.0004 (WPL) 0.00002 (GPL)
L	Lewisite	1,400 (provisional)	1	1,000 (provisional)	1	5,000 to 10,000	1	-		over 1,500	2	less than 300[2]	2	0.003 (STEL)
HN-1	Nitrogen Mustard	1,400 (provisional)	1	1,000 (provisional)	1	10,000 (provisional)	1	-		9,000	2	200	2	-
HN-3	Nitrogen Mustard	1,400 (provisional)	1	1,000 (provisional)	1	10,000 (provisional)	1	-		2,500	2	200	2	-
CG	Phosgene	-		1,500	1	-		1,600	2	-		-		0.4 (OSHA PEL)
CK	Cyanogen Chloride	-		11,000	2	-		7,000	2	-		-		-
CN	Chloroacetophenone	-		7,000 dispersed from solvent 14,000 dispersed from thermal grenade	2 2	-		80	2	-		-		-
DM	Adamsite	-		variable (average = 11,000)	2	-		22 to 150	2	-		-		-
PS	Chloropicrin	-		2,000	2	-		-		-		-		0.7 (OSHA PEL)
	Chloroform	-		-		-		-		-		-		49 (ACGIH TLV)
	Diethyl Malonate	-		-		-		-		-		-		-

Source:
1 FM 3-11.9, 2005
2 FM 3-9, 1990

5.3.1.7 In addition to natural hydrolysis, mustard also degrades in the presence of decontaminants; the primary decontaminants being supertropical bleach (STB) - a solution containing hypochlorite, and Decontaminating Solution 2 (DS2) - composed of diethylenetriamine, ethylene glycol monomer ether, and sodium hydroxide. Mustard decontamination produces many of the same products observed during hydrolysis. Decontamination of mustard with STB or calcium hypochlorite results in essentially complete mineralization to carbon dioxide, water, and inorganic substances, if the reaction is complete. Incomplete reaction may produce intermediate compounds such as mustard sulfoxide, mustard sulfone, and chloroform. Reaction of mustard with DS2 is rapid at moderate temperatures. If the reaction is complete, only divinyl sulfide is produced. If the reaction is incomplete, divinyl sulfide, 2-chloroethyl vinyl sulfide, TDG, and possibly hydroxyethyl vinyl sulfide are formed. Thermal destruction was also used as a method of decontamination. Heating mustard to its boiling point results in degradation and the formation of products, such as 1,4-dithiane, which has a strong garlic and mustard odor (MacNaughton *et al.*, 1994; MacNaughton and Brewer, 1994).

5.3.1.8 At moderate temperatures, mustard deposited on the surface of soil will evaporate within 30 to 50 hours, depending on weather conditions. Although photodegradation is not considered an important factor, mustard vapor will react with radicals in the atmosphere resulting in a half-life of 1.4 days. Mustard buried deep in the soil where it cannot vaporize or undergo weathering has been known to remain undecomposed for years. In soil systems where water only slowly diffuses through the soil matrix, hydrolysis of bulk mustard would be expected to be reduced. For situations where the mustard is not in droplets but dispersed or absorbed by the soil, hydrolysis would be expected to proceed if sufficient water is present (Munro, *et al*., 1999; MacNaughton and Brewer, 1994).

5.3.1.9 Limited information on microbial degradation of mustard indicates that mustard is a cell poison and inhibits bacterial growth. Bacterial degradation is a minor factor compared to hydrolysis and other reactions (MacNaughton *et al.*, 1994).

5.3.1.10 Mustard hydrolysis products such as TDG are all more water soluble than mustard and would tend to migrate at a higher rate than the parent compound. The formation of polymers at the surface of mustard in quiescent conditions and the concentration of TDG in the surface/water interface retards the solvation of mustard; pockets of pure mustard have been found even under water (MacNaughton *et al.*, 1994). TDG itself is resistant to hydrolysis and photolysis. Unfortunately, TDG is not unique to mustard breakdown since it has been used commercially as a solvent in anti-freeze solutions, in dyestuffs for printing, and as a co-stabilizer in the production of polyvinyl chloride (Munro, *et al*., 1999).

5.3.1.11 Pure 1,4-dithiane is a volatile crystalline organo-sulfur compound. It may leach to groundwater because of its moderate water solubility and low soil absorption coefficient. Concentrations have been found in groundwater at Rocky Mountain Arsenal and at Aberdeen Proving Ground (Munro, *et al*., 1999).

5.3.1.12 Studies of the environmental toxicity of sulfur mustard have demonstrated that it is extremely toxic to all species, but its distribution is limited by its low solubility. In studies involving a variety of aquatic species, fish were demonstrated as being more sensitive than phytoplankton and higher aquatic plants. Few data are available on intermediate breakdown products; however, some degradation products such as vinyl sulfoxide and 2-chloroethyl vinyl sulfoxide have been used as experimental pesticides. 1,4-dithiane did not inhibit the growth of plants, nor was it toxic to bacteria. TDG is practically nontoxic to aquatic organisms and terrestrial crops (Munro, *et al*., 1999). A brief summary of the persistence of mustard is provided in Table 5.3.

Table 5.3
Persistence of Mustard (H, HS, HD)

Summary
General: Mustard is the most prevalent chemical in CAIS, being found in all types of sets. H will persist in the environment for years under some conditions.
Ground Surface: H will evaporate within a few days.
Soil Burial: Buried deep in the soil, H cannot vaporize or undergo weathering; it has been known to last for years.
Surface Water: Pure H dumped in seawater sinks to the bottom where it slowly dissolves. Any surface film would degrade or volatilize within days. H can remain stable underwater for years in low temperatures if there is little turbulence or mixing.
Groundwater: H is not transported by groundwater. However, it degrades into the breakdown products, TDG and 1,4-dithiane, which are soluble and can be found in groundwater.

5.3.2 Lewisite (L or M-1)

5.3.2.1 Lewisite (L or M-1) is an organic arsenical blister agent in the form of an amber to dark brown (colorless when pure), oily liquid with a geranium-like odor. Lewisite used as a chemical agent consists of dichloro-2-chlorovinylarsine, tris(2-chlorovinyl)arsine, bis(2-chlorovinyl)chloroarsine, and arsenic trichloride. Originally found in 1904, it was rediscovered in 1918 by Captain W. Lee Lewis at the Catholic University in Washington, D.C. After producing 150 tons of Lewisite too late to be used in World War I, the U.S. destroyed its supply; however, other nations began production in the 1920s and 1930s. Stabilizers are normally added to Lewisite to prevent decomposition in munitions due to reaction with iron. Lewisite has a much lower freezing point than mustard, -48.5 to 28.8^{o}F (-44.7 to -1.8^{o}C), depending on purity and isomers present. In CAIS, Lewisite was only found absorbed in charcoal (K955 and Navy X sets) or as a 5% solution in chloroform in the K951/K952 sets.

5.3.2.2 Lewisite is a strong blister agent that also causes pulmonary edema, diarrhea, and low blood pressure. Lewisite is rapidly absorbed through the skin and causes injury immediately upon contact. The contact hazards of L are similar to mustard but occur much more rapidly. Reddening of the skin occurs within 30 minutes, but blistering does not appear until after 13 hours. Liquid L causes an immediate searing sensation in the eye and permanent loss of sight if not decontaminated immediately. Inhalation of high

concentrations of L may be fatal within minutes. Ingestion of Lewisite causes immediate symptoms of severe salivation, nausea, vomiting, and bloody diarrhea, possibly being fatal within hours. Systemic arsenic intoxication can also occur (MacNaughton *et al*., 1994).

5.3.2.3 Because of the rapid conversion of Lewisite to 2-chlorovinyl arsenious acid (CVAA) upon contact with the human body, the reported toxic properties of Lewisite may actually be those of CVAA. 2-chlorovinylarsine oxide (CVAO) reportedly has vesicant properties; however, it also has an acute toxicity. CVAA has a moderately-high acute toxicity. No data are available for chronic toxicity or carcinogenicity (Munro, *et al*., 1999).

5.3.2.4 Although only slightly soluble in water, Lewisite has a high rate of hydrolysis, which forms hydrochloric acid (HCL) and CVAO (also known as Lewisite oxide). The hydrolysis of Lewisite is complex with a number of reversible reactions. Breakdown products consist of intermediate products dihydroxy-2-chlorovinylarsine, CVAO, CVAA, and sodium arsinite; breakdown proceeds until it eventually results in arsine oxide. Lewisite is readily oxidized to CVAA by seawater and a variety of oxidants. Lewisite is readily soluble in hydrocarbon solvents such as alcohols, gasoline, and chlorocarbons. The absorption of UV light indicates that Lewisite may undergo photodegradation (MacNaughton *et al*., 1994).

5.3.2.5 CVAA is water soluble and nonvolatile breakdown product of Lewisite.. Little is known of the persistence of CVAA and CVAO in the environment (Munro, *et al*., 1999).

5.3.2.6 CVAO damages the skin and is absorbed into the bloodstream where it produces systemic effects typical of arsenical compounds. The oxidation product of CVAO is CVAA, which has markedly reduced toxicity (MacNaughton *et al*., 1994).

5.3.2.7 Recommended decontaminants for use on Lewisite include Super Tropical Bleach (STB), Decontaminating Solution 2 (DS-2), and alkaline solutions. In addition, hypochlorite and thermal destruction are also used for decontamination.

5.3.2.8 In soil, Lewisite would be expected to convert to CVAO even in arid conditions because it reacts readily with moisture. Although relatively nonvolatile, it is more volatile than mustard. Lewisite applied directly to soil has been shown to be more persistent than mustard, possibly explained by the slow oxidation to the inorganic arsenic. CVAO is water soluble and may be microbially oxidized. CVAO would be transported by groundwater or leached by precipitation (MacNaughton *et al*., 1994).

5.3.2.9 In the course of complete Lewisite mineralization, inorganic arsenic compounds can be formed and have been found in areas of past Lewisite releases. Aside from its natural occurrence, arsenic may also be present in the environment as a result of past use of arsenical herbicides. Limited data are available for toxicity of Lewisite in the environment. Some data exist showing that Lewisite is toxic to fish; however, toxicity

decreases as hydrolysis and oxidation of Lewisite and its breakdown products progresses. For aquatic plants, Lewisite inhibited the growth of phytoplankton and was toxic to water milfoil, parrots feather, and water crowfoot. Lewisite is extremely phytotoxic, which has been demonstrated in the death of vegetation in Lewisite shell target areas. The few data available for CVAA indicate it was considerably less toxic to aquatic organisms than Lewisite. Hydrolysis of Lewisite will yield arsenical compounds that persist in the environment. Arsenic will bioaccumulate through food chains where Lewisite will not (Munro, *et al*., 1999). A brief summary of the persistence of Lewisite is provided in Table 5.4.

Table 5.4
Persistence of Lewisite (L)

Summary
General: Lewisite in CAIS is found only as a 5% solution in K951/K952 and K953/K954 sets and absorbed in charcoal in the K955 and Navy X sets. L rapidly hydrolyzes under most conditions. L is extremely phytotoxic and produces arsenical compounds that persist in the environment. Breakdown product CVAO is extremely toxic. CVAA is less toxic.
Ground Surface: L is more persistent than H, slowly oxidizing to inorganic arsenic.
Soil Burial: L will convert to CVAO even in arid conditions. CVAO will slowly oxidize to CVAA.
Surface Water: L will rapidly convert to CVAO. In seawater, CVAO will rapidly oxidize to CVAA.
Groundwater: L will rapidly hydrolyze to CVAO in water. CVAO is water soluble and would be leached by precipitation and transported by groundwater.

5.3.3 Nitrogen Mustards (HN-1 and HN-3)

5.3.3.1 First produced as chemical weapons in the 1920s and 1930s, nitrogen mustards were included in CAIS because of the potential for their use by enemy forces. Nitrogen mustard (HN-1 and HN-3) are blister agents consisting of colorless to yellow or brown oily liquids with a faint fishy or musty odor (HN-3 is colorless with no odor, when pure). HN-1 is composed of ethyl bis(2-chloroethyl)amine. HN-3 consists of tris(2-chloroethyl)amine. Both types are colorless and odorless oily liquids when freshly distilled; however, within days, HN-3 takes on a yellow to brown color. HN-1 is only found as a 10% solution diluted with chloroform (K953/K954) or absorbed in charcoal (Navy X Sets). HN-3 is only found absorbed in charcoal in the Navy X Sets.

5.3.3.2 Nitrogen mustards are highly toxic vesicant agents with strong alkylating activity and significant systemic toxicity. The vapors of HN-1 are irritating to the eyes and nasal membranes even in low concentration. The irritation appears in a shorter time than that from a similar exposure to H. HN-1 is a vesicant (blister agent) and alkylating agent producing cytotoxic action on the blood-forming tissues. HN-1 is not naturally detoxified by the body; therefore, repeated exposure produces a cumulative effect. For HN-3, blistering of the skin may occur after liquid exposure, severe or persistent exposure, or vapor condensation in sweat. Usually a rash will develop from liquid

contamination within an hour, replaced by blistering between six and twelve hours after exposure. HN-3 interferes with hemoglobin functioning in the blood, hindering the production of new blood cells and destroying white blood cells. The HN-1 breakdown product, diethanolamine (DEA), is a severe eye and skin irritant and is moderately toxic by ingestion and very mildly toxic through dermal contact. DEA also shows evidence of carcinogenicity in mice. The HN-3 breakdown product, triethanolamine (TEA), is a mild skin irritant and mild to severe eye irritant. TEA shows very low acute toxicity by oral and dermal exposure routes (Munro, *et al*., 1999; USACHPPM, undated).

5.3.3.3 Based on chemical and physical properties, such as volatility and susceptibility to hydrolysis, HN-3 can be considered environmentally persistent and HN-1 can be considered moderately persistent. Nitrogen mustards are unstable in the presence of light and heat, degrading even under ideal storage conditions with degradation accelerating in the presence of water. Because the volatility of HN-3 is limited, dangerous concentrations are not normally found in the atmosphere; however, HN-1 is more volatile. Neither compound would readily volatilize from water or moist soil. HN-3 in the atmosphere is predicted to react with photochemically-produced hydroxyl radicals resulting in a half-life of 5 hours. Based on its similar chemical structure, HN-1 would also be photolytically degraded (Munro, *et al*., 1999).

5.3.3.4 Nitrogen mustards are sparingly soluble in water with HN-3 hydrolyzing more slowly than HN-1; however, hydrolysis is expected to be a major fate process if released to either soil or water, especially under weakly alkaline conditions. In weakly alkaline soil, hydrolysis of HN-3 proceeds quickly and within 24 hours is 90 to 95% complete. For HN-1, solubility increases with decreasing temperature; one study calculated a half-life of 12.5 days at 5 ºC for HN-1 and all of its toxic hydrolysis products. The rate of hydrolysis in freshwater and seawater are expected to be similar. If released to the atmosphere, HN-3 is expected to degrade rapidly with a half-life of 5 hours (Munro, *et al*., 1999; NIOSH, 2005a; NIOSH, 2005b).

5.3.3.5 While both HN-1 and HN-3 produce intermediary breakdown products, the final hydrolysis products are DEA for HN-1 and TEA for HN-3. Both of these compounds have industrial uses, so their presence in the environment would not be unique to chemical agent contamination. DEA released to soil or water is expected to biodegrade with a half-life of a few days to weeks depending on microbial acclimation. Since DEA is miscible with water, it is expected to leach through soil; although, some may adsorb to organic material in the soil and water. The half-life of DEA vapor in the atmosphere is estimated at 4 hours. TEA is documented as having similar fate properties as DEA (Munro, *et al*., 1999).

5.3.3.6 While intermediate breakdown products are of moderate to high toxicity and irritancy to mammals, the later products are generally of low acute toxicity to mammals and aquatic organisms. Nitrogen mustards were less toxic than sulfur mustard to phytoplankton and higher aquatic plants. HN-1 and HN-3 as well as DEA and TEA are

not expected to bioaccumulate in aquatic organisms (Munro, *et al*., 1999). A brief summary of the persistence of nitrogen mustards is provided in Table 5.5.

Table 5.5
Persistence of Nitrogen Mustards (HN-1, HN-3)

Summary
General: Both HN-1 and HN-3 are found absorbed in charcoal in the "sniff sets." HN-1 is found in 10% solution in K953/K954 sets. HN-1 breaks down to DEA, which is a severe eye and skin irritant. HN-3 breaks down to TEA, which is mild skin irritant and a mild to severe eye irritant.
Ground Surface: Nitrogen mustards are unstable in the presence of light and heat. Both HN-1 and HN-3 will degrade by hydrolysis. Both DEA and TEA will degrade in days to weeks.
Soil Burial: Both HN-1 and HN-3 will degrade by hydrolysis. DEA is miscible in water and expected to leach through soil. Both DEA and TEA will degrade in days to weeks.
Surface Water: Both HN-1 and HN-3 will degrade by hydrolysis. The rate of hydrolysis in freshwater and seawater are expected to be similar. Both DEA and TEA will degrade in days to weeks.
Groundwater: Both HN-1 and HN-3 will degrade by hydrolysis. Both DEA and TEA will degrade in days to weeks.

5.3.4 Chloropicrin (PS)

5.3.4.1 PS is a nonpersistent tearing or choking agent in the form of a colorless to faint yellow liquid with a stinging, pungent odor. Chloropicrin was first used as a chemical warfare agent in World War I by Russia. During World War I, PS was frequently mixed with other chemicals because it could rapidly penetrate some of the early gas masks. It was also employed in various types of pesticides for agriculture, where it is known as trichloronitromethane or nitorchloroform. PS is a nonpersistent tearing or choking agent and was packaged in CAIS as a 50 percent dilute solution with chloroform (K951/K952) or absorbed in charcoal (K955 and Navy X sets).

5.3.4.2 PS is a powerful irritant whose vapors cause nose and throat irritation, coughing and vomiting. As an eye irritant, it produces immediate burning, pain, and tearing. Even in very limited concentration, PS causes the eyelids to close. In high concentrations, PS damages the lungs, causing pulmonary edema. It is very soluble in fats and oils, and different organs absorb it. In liquid form, PS causes severe burns on the skin that generally result in blisters and lesions (FM 3-9, 1990).

5.3.4.3 PS remains unchanged in the soil for varying lengths of time, depending on soil texture and moisture. The half-life of PS can range from less than one hour to 20 days. PS undergoes photo decomposition in the vapor phase and therefore will degrade at or near the soil surface. In sandy loam soil under aerobic conditions, PS degrades primarily to carbon dioxide with a half-life of 4.5 days. Under anaerobic conditions, nitromethane is the principal degradate with a half-life of 4.5 days. In sandy loam soil under aerobic conditions, PS degrades primarily to carbon dioxide with a half-life of 4.5

days. Under anaerobic conditions, PS degrades principally to nitromethane also with a half-life of 4.5 days. PS decomposes into chlorine gas and nitrogen oxide near open fires, producing toxic fumes. PS is formed in the chlorination of drinking water and wastewater. If released in water, it readily volatilizes with modeled half-lives of 4.3 hours for rivers and 5.2 days for lakes. It photodegrades in near-surface water with a half-life of about 3 days. PS is also relatively soluble in water and may be leached from soil by the rain. In the atmosphere, PS photolyzes with a half-live of about 20 days, producing phosgene and nitrosyl chloride (HSDB, 2005b).

5.3.4.4 When applied to soil as a soil sterilant, PS will both rapidly volatilize and leach. PS will also photolyze at the soil surface. A brief summary of the persistence of PS is provided in Table 5.6.

Table 5.6
Persistence of Chloropicrin (PS)

Summary
General: PS is nonpersistent. PS is found as a 50% solution in K951/K952 sets and absorbed on charcoal in K955 and Navy X Sets. PS degrades to carbon dioxide or nitromethane depending on conditions.
Ground Surface: PS rapidly volatilizes and photodegrades.
Soil Burial: PS rapidly volatilizes and degrades with a half-life of about 4.5 days.
Surface Water: Although relatively soluble, PS volatilizes and photolyzes with half-lives of a few days.
Groundwater: PS volatilizes from water.

5.3.5 Phosgene (CG)

5.3.5.1 Phosgene, or carbonyl chloride (CG), is a highly toxic gas used as a choking agent. Below 47°F, it forms a fuming liquid. CG was used extensively as a filler in artillery shells in World War I, potentially being responsible for 80% of the deaths due to chemical weapons. Phosgene is nonpersistent and disperses rapidly when released to the atmosphere. CG has an odor of new-mown hay or rotting fruit; although even at lethal concentrations, it may be difficult to detect. CG, also known as carbonyl chloride, is widely used in industry for the manufacturing of dyes, coal tar, pesticides, and pharmaceuticals. CG is found in the K951/K952 and K953/K954 sets.

5.3.5.2 Phosgene is a severe eye and skin irritant and is highly toxic by inhalation. Acute exposure results in respiratory and circulatory failure. Initial effects are transient irritation of the eyes, nose, and upper airways; otherwise the effects do not appear until 2 to 24 hours after exposure. Exposure to phosgene can be fatal with most deaths occurring within 24 hours. When inhaled, CG goes into the lungs and damages the alveoli, breaking down the membranes. The result is buildup of fluid in the lungs and blockage of oxygen transport from air to blood. Chronic exposure can cause emphysema and dermatitis (MacNaughton *et al*., 1994).

5.3.5.3 The solubility of phosgene in water is limited but it is readily absorbed in hydrocarbon solvents. Phosgene hydrolyzes rapidly in water, even at low temperatures. Phosgene completely hydrolyzes to carbon dioxide and HCl, which are considered nontoxic. In the air, CG is relatively stable, decreasing noticeably only after several hours (MacNaughton *et al*., 1994).

5.3.5.4 Factors such as soil interaction, biodegradation, and environmental transport are dominated by the high volatility of CG and its rapid hydrolysis (MacNaughton *et al*., 1994). A brief summary of the persistence of CG is provided in Table 5.7.

Table 5.7
Persistence of Phosgene (CG)

Summary
General: CG is a nonpersistent gas or rapidly volatilizing liquid. CG is found only in the K951/K952 sets.
Ground Surface: CG disperses as a gas. In air, it breaks down after several hours.
Soil Burial: CG disperses as a gas. It rapidly hydrolyzes with water to form carbon dioxide and HCl.
Surface Water: CG disperses as a gas and completely hydrolyzes to form carbon dioxide and HCl.
Groundwater: CG disperses as a gas and completely hydrolyzes to form carbon dioxide and HCl.

5.3.6 Cyanogen Chloride (CK)

5.3.6.1 Cyanogen chloride (CK) is a blood agent in the form of a volatile, colorless liquid with a pungent, biting odor. CK is a liquid below 55 deg F. Because of its volatility, CK is considered a nonpersistent agent. Originally used by the French in World War I, CK has many industrial uses including the manufacturing of synthetic rubber. During World War II, the U.S. Army produced CK for use in chemical munitions. CK is found only as a pure liquid in the K953/K954 sets.

5.3.6.2 CK is highly toxic as a gas or liquid, and is converted in the body to hydrocyanic acid and then detoxified to thiocyanate. CK is called a blood agent not because it poisons the blood but because it is distributed throughout the body by the blood. The toxic effects of CK are similar to cyanide, producing respiratory failure and blocking cellular metabolism.

5.3.6.3 The primary hydrolysis product of CK, cyanic acid, is toxic by oral and internal routes. Cyanic acid is a vesicant and strong lachrymator, causing severe irritation to the eyes, skin, mucous membranes and respiratory tract. Human ingestion can result in weight loss and eye effects including vision field changes (Munro, *et al*., 1999).

5.3.6.4 At moderate temperatures, CK is an extremely volatile liquid. Because of its extreme volatility and relatively rapid rate of hydrolysis in water, CK is not expected to persist in surface waters. Hydrolysis products range from cyanic and hydrochloric acids to slowly produce carbon dioxide and ammonium chloride. Since CK had a tendency to spontaneously polymerize, a stabilizer such as sodium pyrophosphate was added to increase the shelf-life in storage (Munro, *et al*., 1999; Croddy, 2002).

5.3.6.5 Cyanogen chloride from sources other than chemical agents may be present in surface waters, being formed by the action of active chlorine on dissolved or suspended organic matter. Disinfection of drinking water by chlorination results in the formation of chlorinated byproducts including cyanogen chloride (Munro, *et al*., 1999).

5.3.6.6 Information on the fate of CK in soil is not available; however, its fate in soil would probably exhibit volatilization and hydrolysis similar to surface water. CK is extremely toxic to aquatic organisms (Munro, *et al*., 1999). A brief summary of the persistence of CK is provided in Table 5.8.

Table 5.8
Persistence of Cyanogen Chloride (CK)

Summary
General: CK is nonpersistent. CK is found only in the K953/K954 sets. It is a liquid that rapidly forms a gas. CK hydrolyzes to form cyanic acid, which is toxic and produces severe eye, skin, and respiratory irritation.
Ground Surface: CK disperses as a gas and rapidly hydrolyzes with water.
Soil Burial: Information on fate in soil is unavailable; CK is expected to exhibit volatilization and hydrolysis is soil is similar to that observed in surface water.
Surface Water: CK is nonpersistent and hydrolyzes rapidly to produce cyanic acid and other compounds which slowly degrade to carbon dioxide ad ammonium chloride.
Groundwater: Expected to be similar to surface water.

5.3.7 Triphosgene

5.3.7.1 Triphosgene is phosgene substitute in the form of a white to off-white crystalline solid. When exposed to moisture in the air triphosgene decomposes to form phosgene. Less hazardous than using phosgene, it was used as a simulant for training. Triphosgene is found only in the K955 and Navy X sets ("sniff sets") in bottles containing 6 grams of the compound.

5.3.7.2 Triphosgene is severely irritating to the eyes, respiratory tract, and skin. It decomposes on contact with water and water vapor to produce phosgene. The reaction rate increases with increasing temperature. In the environment, triphosgene will completely degrade to phosgene within hours to days. A brief summary of the persistence of triphosgene is provided in Table 5.9.

Table 5.9
Persistence of Triphosgene

Summary
General: Triphosgene is found in the K955 and Navy X sets ("sniff sets"). When exposed to moisture in the air, it decomposes to produce CG gas. CG will disperse and hydrolyze rapidly in the environment.
Ground Surface: Triphosgene will completely degrade to CG within hours to days depending on conditions
Soil Burial: Triphosgene will completely degrade to CG within hours to days.
Surface Water: In water, triphosgene will completely degrade to CG within hours.
Groundwater: In water, triphosgene will completely degrade to CG within hours.

5.3.8 Chloroacetophenone (CN)

5.3.8.1 Chloroacetophenone (CN) is a tearing agent (used in "tear gas") in the form of a gray, crystalline solid that has a sharp irritating odor somewhat like apple blossoms. The commercial product, Mace, was essentially CN dissolved in a solvent for spraying assailants. In CAIS, CN is found only as a powder in the "sniff sets" (K955 and Navy X sets).

5.3.8.2 CN quickly irritates the eyes and upper respiratory passages. In higher concentrations, it causes copious tearing; a tingling sensation, irritation, burning, and pain of the nose and throat; and burning and itching on tender areas of the skin, especially areas wet by perspiration. High concentrations can cause blisters. The effects are similar to sunburn but disappear in a few hours. Some individuals experience nausea following exposure to CN (FM 3-9, 1990).

5.3.8.3 In moist soil, volatilization is expected to be an important fate process. CN undergoes hydrolysis very slowly, and the breakdown products are hydrochloric acid and hydroacetophenone. CN is not expected to volatilize from dry soil. In water, CN is not anticipated to adsorb to suspended solids and sediment. Volatilization from water is expected with modeled half-lives of 14 days for river models and 110 days for lake models. Biodegradation is not expected. In the atmosphere, CN is expected to exist only in its vapor-phase due to its vapor pressure. CN vapor is degraded by hydroxyl radicals and may degrade due to photolytic reactions (HSDB, 2005a). A brief summary of the persistence of CN is provided in Table 5.10.

Table 5.10
Persistence of Chloroacetophenone (CN)

Summary
General: CN is found as a powder in the K955 and Navy X sets ("sniff sets"). CN breaks down to hydrochloric acid and hydroacetophenone.
Ground Surface: CN hydrolyzes very slowly; CN is not expected to volatilize from dry soil.
Soil Burial: CN hydrolyzes very slowly; CN is not expected to volatilize from dry soil.
Surface Water: Volatilization of CN from water is expected to take weeks to months. CN hydrolyzes very slowly; CN is not expected to volatilize from dry soil.
Groundwater: Volatilization of CN from water is expected to take weeks to months. CN hydrolyzes very slowly; CN is not expected to volatilize from dry soil.

5.3.9 Adamsite (DM)

5.3.9.1 Adamsite (known as diphenylaminochloroarsine or DM) is a sternutator, or vomiting agent, in the form of light green to yellow crystals with no odor. Adamsite was first produced during World War I, when it was disseminated as an aerosol. DM is found only in the "sniff sets" (K955 and Navy X sets).

5.3.9.2 DM causes almost immediate extreme pain to the eyes, nose, and throat. These symptoms can be followed by vomiting and bowel constriction after a few minutes exposure. An incapacitating dosage is detoxified within one to two hours (FM 3-9, 1990).

5.3.9.3 Hydrolysis is rapid when in aerosol form. When solid DM is covered with water, a protective oxide coating forms that hinders further hydrolysis. The hydrolysis products are diphenylarsenious oxide and hydrochloric acid. The oxide is very poisonous if ingested. Adamsite hydrolyzes slowly and is persistent in soil. Adamsite is also persistent on surfaces such as wood, masonry, rubber, and paint. DM in solid form has a negligible vapor pressure at ambient temperatures and forms no appreciable vapor. When heated, DM first vaporizes and then condenses to form aerosols which have a short persistence in the environment. A brief summary of the persistence of DM is provided in Table 5.11.

Table 5.11
Persistence of Adamsite (DM)

Summary
General: DM is found only as a powder in the K955 and Navy X sets. Hydrolysis products are hydrochloric acid and diphenylarsenious oxide, which is toxic if ingested. Only limited data on the fate of DM are available.
Ground Surface: DM is persistent but breaks down slowly by hydrolysis.
Soil Burial: DM is persistent but breaks down slowly by hydrolysis.
Surface Water: When solid DM is covered by water, a protective oxide layer forms that hinders further hydrolysis.
Groundwater: When solid DM is covered by water, a protective oxide layer forms that hinders further hydrolysis.

5.3.10 Chloroform

5.3.10.1 Chloroform is used to dilute certain chemical agents and industrial chemicals in the K951/K952 and K953/K954 sets. It occurs naturally and also enters the environment as a manmade pollutant as a result of chlorination of drinking water, municipal sewage, cooling water in electric power generating plants, atmospheric photodegradation of trichloroethylenes, and auto exhaust.

5.3.10.2 Chloroform is a commonly used solvent with well-known toxicological properties. Chloroform is a central nervous system toxicant, causing lassitude and mental dullness in humans at 80 to 240 ppm and clinical anesthesia at 10,000 ppm. Death can result from respiratory depression, cardiac arrest, or from liver toxicity associated with anesthetic use. Chloroform is a skin and eye irritant and causes corneal injury in humans. Liver and kidney damage can result from acute exposure. It is a suspected human carcinogen of moderate potency for lifetime oral exposure.

5.3.10.3 Since chloroform has a hydrolysis half-life of 1850 yrs at 25 deg C and pH 7, hydrolysis will not be an environmentally important loss process. Volatilization from moist soil is expected to be a major fate process. In a study of chloroform residence time in soils, chloroform was found to have a half-life of 0.3 days when applied 1 cm deep into soil and 1.4 days when applied 10 cm deep. It was also classified as a "very short-lived" chemical in soil matrices primarily due to its high volatility. Chloroform may also volatilize from dry soil surfaces based upon its vapor pressure. Chloroform is expected to have moderate mobility in soil. Under normal environmental conditions, chloroform is not expected to undergo biodegradation in soil.

5.3.10.4 If released into water, chloroform is not expected to adsorb to sediment and suspended solids. Volatilization half-lives for a river model and a lake model are 1.3 hours and 4.4 days, respectively. In the atmosphere, chloroform will exist in the vapor phase and slowly photolytically degrade. A brief summary of the persistence of chloroform is provided in Table 5.12.

Table 5.12
Persistence of Chloroform

Summary
General: Chloroform is found as a solvent in K951/K952 and K953/K954 sets. Chloroform is a suspected human carcinogen
Ground Surface: Chloroform volatilizes fairly rapidly. Hydrolysis is not an important fate process.
Soil Burial: Chloroform volatilizes fairly rapidly. Hydrolysis is not an important fate process.
Surface Water: Chloroform is lost from water by volatilization. Hydrolysis is not an important fate process in water.
Groundwater: Chloroform is lost from water by volatilization. Hydrolysis is not an important fate process in water.

5.3.11 Diethyl Malonate

5.3.11.1 Diethyl malonate is used as a simulant for the nerve agent tabun (GA) in K953/K954 CAIS. It is a colorless liquid with a sweet, green apple, fruity odor, and it occurs naturally in grapes and strawberries. Diethyl malonate is used in perfumes and to synthesize other compounds such as barbiturates, artificial flavorings, vitamin B1 and vitamin B6.

5.3.11.2 Diethyl malonate is an irritant to the eyes, respiratory system, and skin. Ingestion causes sore throat, abdominal pain, and diarrhea. It is considered safe in low concentrations; a 4% solution causes no irritation or sensitization in humans (Good Scents Company, 2006). Breakdown products consist of carbon monoxide and carbon dioxide. Information on the environmental fate of diethyl malonate has not been found.

SECTION 6
BASELINE RISK ASSESSMENT

6.1 INTRODUCTION

6.1.1 The purpose of the baseline risk assessment is to define the current human health and ecological risks associated with potentially remaining CAIS at a site. In general, the objectives of a baseline risk assessment may be attained by identifying and characterizing the following:

- Toxicity levels of hazardous substances present in relevant media (e.g., air, ground water, soil, surface water, sediment, and biota).
- Environmental fate and transport mechanisms within specific environmental media such as physical, chemical, and biological degradation processes and hydrogeological conditions.
- Potential human and environmental receptors.
- Potential exposure routes and extent of actual or expected exposure.
- Extent of expected impact or threat and the likelihood of such impact or threat occurring (i.e., risk characterization).
- Levels of uncertainty associated with the above items.

6.1.2 Normally, a conceptual site model is developed and refined to help focus investigation efforts; however, with a generic study such as this one, site-specific details on the concentrations of chemicals, areal extent of contamination, numbers and types of receptors, and the nature of exposure pathways are all unavailable. However, a simple generic model can be applied. In this model, an exposure can only occur if intrusive work is being done that encounters CAIS. Exposure would be via inhalation and dermal contact. The receptors are site workers and humans and the ecological receptors in the immediate vicinity of the release. Left undisturbed, CAIS present at a site present no significant hazard to humans or the environment. An example of a conceptual site model for CAIS is provided in Appendix B.

6.1.3 The problem with CAIS is that any investigation to detect their presence is highly likely to have negative results; conversely, even though negative results are obtained, undetected CAIS may still be present as a source of contamination. Even investigations that are seemingly successful due to the recovery of CAIS pigs may still leave undetected bottles or ampoules from CAIS in the investigation area. With these considerations, a general risk evaluation for CAIS is provided in the sections below.

6.2 HUMAN HEALTH AND ENVIRONMENTAL RISK CHARACTERIZATION

The human health and environmental risk characterization has five phases:

1. Identify the potential chemicals of concern,
2. Identify potential exposure pathways,
3. Exposure assessment,
4. Exposure characterization,
5. Evaluation of uncertainty.

6.2.1 Potential Chemicals of Concern

6.2.1.1 The following paragraphs provide a discussion of the chemical and physical properties of the compounds contained in the various types of CAIS. Descriptions of the various types of CAIS are provided in Section 2. A discussion of the fate and transport properties of the various chemicals is provided in Section 5. Table 6.1 shows which compounds are associated with which type of CAIS.

Table 6.1
Hazardous Chemicals contained in CAIS

Compound	Type of CAIS					
	K941	K942	K951/K952	K953/K954	K955	Navy X Sets
H, HD, HS	P	P	D	D	C	C
L, M-1			D	D	C	C
HN-1				D		C
HN-3						C
PS			D		C	C
CG			P	P		
CK				P		
Triphosgene					P	P
CN					P	P
DM					P	P
Chloroform			S	S		
Diethyl malonate				P*		

Notes: P = in pure or undiluted form; D = diluted; C = absorbed in charcoal; S = used as a solvent for other chemicals.
*Assumed to be pure (non-hazardous). K945 sets are not shown.

6.2.1.2 In summary, the hazardous chemicals contained in CAIS can be addressed in terms of 1) the chemicals that persist in intact containers and 2) the fate of chemicals

released to the environment sometime in the past, such as during chemical warfare training.

6.2.1.3 All of the chemicals found in intact CAIS containers have the potential to remain at least partially un-degraded. Even when sealed in glass ampoules and bottles, chemicals can degrade due to impurities present from the manufacturing process and in the container headspace, and due to temperature changes and exposure to light. Because most CAIS remaining at a site are expected to be buried, degradation due to impurities and environmental variations are expected to progress to a point of relative stability. In any case, the degree of CAIS chemical degradation will be dependent on time and the environment.

6.2.1.4 When released from a container to the environment, the various CAIS chemicals will have different degrees of persistence depending on the chemical and on environmental conditions. Section 5 includes a summary of the persistence and fate of the various CAIS constituents. Depending on conditions, the most persistent CAIS chemicals are mustard, Lewisite breakdown products, nitrogen mustard breakdown products, chloroform, and Adamsite. Other CAIS chemicals, such as phosgene, triphosgene, cyanogen chloride, and chloropicrin are nonpersistent.

6.2.2 Identification of Potential Exposure Pathways

6.2.2.1 In order for an exposure pathway to be complete (i.e., potential for exposure to occur), the following elements must be present:

- A source (presence of CWM);
- A pathway; and
- A receptor.

6.2.2.2 Specific areas of potential CWM contamination have not been identified at the suspect CWM site; however, there is a remote chance that buried CAIS may remain in portions of the property that are still undeveloped. Therefore, potential sources consist of the CAIS constituents identified above.

6.2.2.3 An exposure pathway is defined by four elements (U.S. EPA, 1988):

- A source and mechanism of chemical release to the environment;
- An environmental transport medium (e.g. soil, air) for the released constituent;
- A point of potential contact with the contaminated medium (exposure point); and
- An exposure route (e.g., ingestion, dermal contact, inhalation) at the exposure point.

6.2.2.4 The current and future exposure scenarios for the suspected CWM sites are discussed below.

- **Air as an Exposure Pathway:** Exposure of utility workers, construction workers, maintenance workers, or passing pedestrians via inhalation of CAIS constituents released as a result of excavation activities is considered a potential exposure pathway. Exposure may result directly from CAIS constituent vapors or from contaminated dust particles. Exposure due to residual CAIS chemicals from the air is unlikely to have a significant exposure potential.

- **Soil as an Exposure Pathway:** Utility workers, construction workers or maintenance workers may contact soil contaminated with CAIS chemicals via incidental ingestion or dermal contact. Workers could come into direct contact with CAIS chemical-contaminated soil as a result of excavation activities and could ingest contaminants through hand-to-mouth contact.

- **Groundwater as an Exposure Pathway:** Groundwater could potentially be encountered by maintenance or construction workers during excavation activities conducted at a site. Exposure of workers via dermal contact is considered a potential exposure pathway as well as incidental ingestion of groundwater within the work area. In addition, exposure to area residents and business workers via dermal contact or ingestion of chemical agent contaminated groundwater is considered a potential pathway. Although groundwater has been evaluated as an exposure pathway, it is considered unlikely to be impacted by CAIS chemicals and would not be expected to have a significant exposure potential due to the relatively small quantities. Impacts to groundwater would only be expected to be significant in the immediate release area.

- **Surface Water as an Exposure Pathway:** Although some suspected CWM sites will be located in desert areas away from surface water, many sites will have lakes, ponds, creeks or rivers. Therefore, surface water is a potential exposure pathway via dermal exposure, ingestion, or inhalation of vapors from CAIS chemicals dissolved in water, suspended in water, or settled to the bottom. Due to the relatively small quantities of CAIS chemicals, surface water is considered unlikely to be impacted and would not be expected to have a significant exposure potential except in the immediate release area.

- **Ingestion of Fish as an Exposure Pathway:** Exposure to persons ingesting fish contaminated with CAIS constituents is considered a potential exposure pathway. While ingestion of biota as an exposure pathway is considered, it is also considered as unlikely to be impacted and not expected to have a significant exposure potential due to the relatively small quantities. As with

the other exposure pathways, impacts to biota would only be expected to be significant in the immediate release area.

6.2.3 Exposure Assessment

The exposure assessment estimates the extent of human contact with potential chemicals of concern by characterizing potentially exposed receptors, identifying actual or potential routes of exposure, and estimating the extent of human exposure. The current and future receptors and associated routes of exposure are identified in Table 6.2. Table 6.2 evaluates the exposure pathways for various receptors. In this case, the construction worker is assumed to be conducting some form of intrusive activities that may potentially encounter buried CAIS ampoules or bottles or CAIS chemicals in the soil. The maintenance worker would only be servicing existing facilities and, therefore, would be less likely to encounter CAIS chemicals. An emergency responder would only be exposed if responding to an emergency involving exposure to CAIS chemicals; however, if such a circumstance occurs, exposure is possible. The category of passersby and pedestrians includes casual visitors who might be exposed due to intrusive activities. Swimmers, boaters, and fishermen would only be exposed if in the immediate vicinity of a release, since the CAIS chemicals are not expected to be persistent in a body of water.

6.2.4 Exposure Characterization

Although no CWM has been identified at the suspected CWM site, the possibility exists for chemical agent contamination, or potential chemical agent contamination to be present due to CAIS remaining at the site. Since no single specific source has been identified, it is assumed that any of the CAIS chemicals could remain at the site and be considered chemicals of potential concern. Analytical data identifying the chemicals of potential concern in site media does not exist since there have been no disposal areas or sources identified at the site; however, the potential exists for contamination to be present in soil, groundwater, surface water, air, and biota. For CAIS, there are two potential types of sources:

1. Old Releases - Chemicals and breakdown products remaining from the use of CAIS during training or previous releases.
2. Buried CAIS - Acute exposure to CAIS chemicals due to breaking a glass container.

Table 6.2
Exposure Assessment

	Construction Worker	Maintenance Worker	Emergency Responder	Passerby or Pedestrian	Swimmers/Boaters	Fisherman	Residents/Business Workers
Acute exposure to vapors due to broken CAIS ampoules or bottles during work activities	**P**	U	U	U			
Dermal contact with CAIS chemicals	**P**	U	**P**	U			
Dermal contact with soil contaminated as a result of broken CAIS ampoules or bottles	**P**	U	**P**				
Incidental ingestion of contaminated soil	U	U	U				
Incidental dermal contact with groundwater	U	U	U				U
Incidental ingestion of groundwater	U	U					U
Dermal contact with contaminated personnel			**P**				
Inhalation of contaminated particulates due to wind erosion during construction activities	U			U			
Dermal contact with CAIS chemicals in surface water					U	U	
Ingestion of surface water contaminated with CAIS chemicals					U	U	
Ingestion of fish contaminated with CAIS chemicals						U	

P = Possible pathway; U = unlikely pathway, needs to be evaluated on a site-by-site basis.

6.2.4.1 Old Releases

Old releases of CAIS chemicals that occurred during military training will consist of a particular set of risks. All nonpersistent chemicals (CG, CK, PS, triphosgene) will have long since been reduced to nonhazardous levels. Chemical agents that were dissolved in a solvent (H/HS, L, HN-1) most likely have volatilized or degraded into breakdown products. Only very small quantities of mustard (H) from decontamination training might remain if missed by decontamination but only under ideal conditions such as in cold, still waters. Chloroform in the soil may persist while gradually volatilizing over time. If released to the environment, chemicals from "sniff sets" would mostly degrade; hazardous chemicals would only remain in very small quantities, if at all. Some compounds, such as DM and CN, would only present a hazard if made airborne as a dust or if direct skin contact to high concentrations is made. It should be noted that CAIS chemicals directly in soil or other media are not classified as CWM by the U.S. Army and, therefore, would fall under HTW investigations unless CWM, such as intact CAIS containers of the types classified as CWM, is also thought to be present.

6.2.4.2 Buried CAIS

The greatest hazard will be from CAIS in loose bottles or ampoules. Chemical agents and industrial chemicals in these containers may persist indefinitely until accidentally broken or opened. The ampoules from the CAIS normally detonated in outdoor demonstrations (K951, K953), bottles from K941 sets and ampoules from K942 sets will mostly likely have been buried as a means of disposal or buried following attempted destruction via burning. Chemicals from "sniff sets" were most likely consumed prior to disposal of the bottles, so the quantities for these agents would be small. All of the reported injuries from accidental exposures to CAIS were from ampoules, and there have been no reports of injuries related to exposure to old releases of CAIS chemicals to the environment. The bottles may contain residual mustard that can cause injury. At the Presidio in California, chemical burns occurred to a person who handled an old K941 bottle without a glove.

6.2.4.3 Effects of Exposure

The limited history of unintentional exposures to CAIS chemicals shows that acute symptoms predominate. Symptoms that have been observed include choking, watery eyes, trouble breathing, blisters, and redness of skin. Persons who have been exposed recover in a short time. One fatality has been unconfirmed as being due to accidental exposure to CAIS chemicals. Given the limited number of exposure incidents and the lack of follow-up examinations, it is difficult to conclude that exposure to CAIS chemicals results in only short term effects. Specific information on the health effects of individual CAIS chemicals is provided in Section 5.

6.2.5 Uncertainty Analysis

Most of the uncertainty in evaluating the hazards due to CAIS lies in the inability to quantify the amounts of chemicals present or determine even if they exist. The other significant uncertainty lies in the lack of information on the locations of outdoor chemical

warfare training or demonstration areas and the locations of CAIS burials. Most of the discussion in this section is based on the relatively conservative assumption that CAIS chemicals are present, although in many cases the quantities of chemicals used were likely very small.

6.3 SUMMARY AND CONCLUSIONS

Based on the foregoing discussion, the greatest risk stemming from CAIS is the potential presence of buried loose bottles and ampoules. If opened or broken, these bottles or ampoules could produce a dangerous release of chemicals. A less significant risk may also remain from small amounts of chemical agents and breakdown products that persist from historical chemical warfare training exercises.

PART II

FEASIBILITY STUDY

SECTION 7
FEASIBILITY STUDY INTRODUCTION

7.1 INTRODUCTION

7.1.1. The feasibility study (FS) is the mechanism for the development, screening, and detailed evaluation of remedial action alternatives. This FS addresses sites categorized as suspect CWM sites where CAIS has been identified as the only potential form of CWM remaining. Sites with other known or suspect CWM are not included as part of this FS.

7.1.2. The Development of Alternatives Phase of the FS process begins when likely response scenarios are first identified. The development of alternatives requires:

1. Identifying remedial action objectives.
2. Identifying potential treatment, resource recovery, and containment technologies that will satisfy these objectives.
3. Screening the technologies based on their effectiveness, implementability, and cost.
4. Assembling technologies and their associated containment or disposal requirements into alternatives for the contaminated media at the site.

7.1.3. The range of alternatives developed to address CAIS under this Programmatic RI/FS is unique in that burial locations are not known nor suspected and technologies for detection are limited or unavailable. This FS provides a detailed analysis of the most promising options to establish the basis for a remedy selection.

7.1.4. The approach will be to prepare a site-specific evaluation that will determine if the site meets the required criteria described in Section 1. Results of the evaluation supported by the Programmatic RI/FS will present the recommendation for the site.

7.2 IDENTIFICATION OF ARARS

7.2.1. Section 121(d)(1) of CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), requires that remedial actions must attain a degree of cleanup that assures the safety of human health and protection of the environment. Moreover, all potential ARARs must be outlined. ARARs include federal standards, requirements, criteria, and limitations under state environmental or facility siting regulations that are more stringent than federal standards.

7.2.2. ARARs are identified on a general and site-specific basis and involve a two-part analysis: first, a determination is made as to whether a given requirement is applicable; if not

applicable, examination is made of whether it is nevertheless both relevant and appropriate. When a requirement is found to be both relevant and appropriate, that requirement must be complied with to the same degree as if it were applicable.

7.2.3. Non-promulgated advisories or guidance documents issued by federal or state governments do not have the status of potential ARARs. However, these "to be considered" (TBC) criteria may be used in determining the necessary level of cleanup for human safety and protection of the environment. Potential site-specific ARARs and TBCs will be evaluated on an individual basis for those sites applicable to the Programmatic RI/FS.

SECTION 8
IDENTIFICATION OF AREAS REQUIRING REMEDIAL ACTION

8.1. As noted previously, this FS is applicable to sites where the evaluation results for suspect CWM indicate the potential presence of CAIS as the sole type of potential CWM. This includes sites where CAIS have been found and a removal action has been completed. This FS is not applicable to sites with known disposal areas or sites with other suspect CWM contamination (such as chemical munitions or bulk containers) in addition to CAIS.

8.2. Field investigation of sites potentially containing CAIS is limited by the lack of identifiable, potential burial sites; therefore, in the absence of an identified burial area, the area selected for remedial action will consist of the entire property. Even though the probability of locating buried CAIS is greater near and within former chemical warfare training areas and near former chemical warfare storage areas, the remainder of the property cannot be ruled out as a location for potential burials.

8.3. If new information on a potential burial location becomes available through newly identified historical records, through environmental investigations, or from an incident where CAIS are encountered, the site will need to be reevaluated for a site-specific intrusive investigation for CAIS.

SECTION 9
REMEDIAL ACTION OBJECTIVES

9.1. INTRODUCTION

The overall remedial action objective (RAO) is to reduce the risk of human exposure via dermal contact, inhalation, and ingestion of chemical agent or chemical agent impacted media.

9.2. EXPOSURE SCENARIO

9.2.1. The greatest risk to human health and the environment associated with CAIS is due to acute exposure from breakage of loose bottles and ampoules. Due to the small amounts of chemicals released during acute exposure incidents, the release of the chemicals to the environment is a lesser hazard. Cleanup of the immediate vicinity of the release can be accomplished for the more persistent agents. The non-persistent chemicals will rapidly volatilize and disperse. This section provides a description of a hypothetical CAIS exposure scenario.

9.2.2. Although the glass CAIS containers are relatively tough, they can be broken by a hard strike with a shovel, the blade of a bulldozer, a backhoe bucket, or being driven over by heavy equipment. Experience with previous releases has shown that the most common scenario for encountering CAIS occurs when excavating for utilities or building foundations. If bottle or ampoule breakage occurs during excavation, workers in the immediate vicinity will be subject to the harmful effects of the chemical release. For the more persistent chemicals, the soil in the immediate vicinity of the broken container will become contaminated.

9.2.3. If the workers recognize that a chemical release has occurred, the managers responsible for the workers will be contacted and a rudimentary investigation will be conducted. During this investigation, it is possible that additional persons might become injured, especially if persistent chemicals have been released. Generally, the exposed workers will be examined by medical authorities and the local police and health departments are usually contacted. At some point, the release will be attributed to chemicals remaining from the former military installation and the Army will be contacted. The elapsed time from the initial exposure to the realization that CAIS chemicals are involved might range from a few hours to several days. Unfortunately, early recognition of the release is important for proper treatment of persons exposed to CAIS chemicals.

9.2.4. Response scenarios for CAIS sites will depend on the type of CAIS discovered. If CAIS classified as CWM are discovered, the 22nd Chemical Battalion (formerly Technical Escort Unit) will respond to address any remaining immediate hazards at the site. The 22nd Chemical Battalion can usually mobilize personnel to the site within one or two days. The 22nd Chemical Battalion personnel will have the proper training to handle chemical agent hazards, and will remove and dispose of any damaged or intact CAIS containers in the immediate vicinity of the incident. They will also gather pertinent facts and write a brief report. If there is evidence of an extended burial or if additional burial sites are thought to exist, the report might make recommendation for further investigation at a later date. If non-CWM CAIS are discovered at a site, the USACE will respond to address the CAIS through a HTW investigation.

9.2.5. A second exposure scenario for sites where CAIS chemicals remain in the ground is as follows. Since CAIS chemicals were used in small quantities, most of the chemicals would be expected to be lost to hydrolysis and volatilization, leaving only trace levels in the soil. The potential exists for globs of mustard to remain from the dumping and burial of the contents of K941 and K942 sets. When such globs are encountered, the scenario would likely follow the course described above for breaking a container. Because of the quantities, use, and properties of CAIS chemicals, a chronic exposure scenario is not anticipated to be significant.

9.2.6. The RAOs will be to reduce the hazards from an exposure scenario such as the one described above. This may be accomplished by the following:

- If the workers and managers responsible for intrusive activities at suspect CAIS sites are educated in the possible hazards, the risk due to exposure can be reduced by understanding that CAIS may remain at the site, avoiding items that may potentially be CAIS, and promptly reporting a possible CAIS exposure incident.

- If emergency responders responding to a CAIS exposure incident understand the range of potential hazards for the site, they can respond with the proper treatment and reduce the extent of potential injuries to exposed persons and also avoid injuries to themselves due to cross-contamination.

- By early recognition of a potential CAIS exposure incident, the incident location can be closed until the Army can respond, avoiding follow-on exposure incidents.

9.2.7. Other means of reducing exposure to CAIS, such as restricting access to hazardous areas, is not feasible where the burial locations are unknown. Generally, if a site has a known or documented burial area, that site is not applicable to this Programmatic RI/FS; however, once the suspected burial area has been investigated and any CAIS found have been removed, the site will become eligible since complete removal of loose CAIS ampoules and bottles cannot usually be confirmed.

SECTION 10
IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

10.1. Because many of the suspected CAIS sites share similar characteristics, they lend themselves to remediation by similar alternatives. EPA has established a number of guidelines for the types of remedial alternatives that should be developed during the detailed analysis stage; they are listed in the National Contingency Plan (40 CFR 300.430(a)(1)) and are summarized as follows:

- Use treatment to address the principal threats posed by a site, wherever practicable.
- Use engineering controls for low, long-term threats or where treatment is impracticable.
- Use a combination of methods, as appropriate, to achieve protection of human health and the environment.
- Use institutional controls (ICs) to supplement engineering controls to prevent or limit exposure to hazardous substances, pollutants, or contaminants. The use of ICs shall not substitute for active response measures as the sole remedy unless such active measures are determined not to be practicable.
- Consider using innovative technologies.
- Return usable ground waters to their beneficial uses wherever practicable.

10.1.2. NCP guidance goes on to state that "the development and evaluation of alternatives shall reflect the scope and complexity of the remedial action under consideration" (40 CFR 300.430(e)). Remedial actions under consideration for the FS are limited because, although CAIS burial is possible, there is no known CAIS chemical contamination. In addition, due to the lack of specific burial locations, the inability to effectively sample or monitor subsurface concentrations of CAIS chemicals, and the technological inability to detect buried glassware, only a limited number of remedial action alternatives are considered for this FS.

10.1.3. Investigation methodologies for locating buried CAIS fall into two distinct categories: direct detection methods and indirect detection methods. Direct detection methods consist primarily of geophysical instruments such as metal detectors, magnetometers, and ground penetrating radar. Excavation as a means of exploration for CAIS burial sites is also a method of direct detection but is considered impractical for all but small investigation areas. Indirect detection methods primarily use remote sensing

such as aerial photographs and satellite images to find indications of burial sites where CAIS may remain. Another possible indirect detection method is to collect environmental samples of soil and groundwater for analysis of chemical agents and agent breakdown products. These remedial technologies and their technological limitations for intrusive investigations to locate buried CAIS are presented in greater detail in Section 3 of this document. This document does not address innovative or developing technologies.

SECTION 11
DEVELOPMENT AND SCREENING OF REMEDIAL ACTION ALTERNATIVES

11.1. DEVELOPMENT OF ALTERNATIVES

11.1.1 This section presents the development and description of response action alternatives that are considered for this FS. Consistent with 40 CFR 300.430, the FS shall include the following:

- Alternatives that are protective to human health and environment by eliminating, reducing, or otherwise controlling risks posed by the site.
- Reasonable numbers and types of alternatives based on the characteristics and complexity of the site, including current site conditions and physical constraints.
- At least one permanent response action alternative to serve as a baseline against which other alternatives shall be evaluated for the purpose of determining whether the response action selected is permanent to the maximum extent practicable.
- Alternatives that consist of one or more response action components, including, but not limited to: components that reduce the hazard (CAIS) at the site and on-site isolation of the hazard (CAIS) with engineering or institutional controls.
- Alternatives that may include remediation levels to define when particular response action components will be used. Alternatives may also include different remediation levels for the same component.

11.1.2. Based on the above requirements, five alternatives, including the NDAI alternative, were developed for consideration. The five alternatives are:

1. NDAI.
2. Access controls.
3. Educational awareness and training.
4. Geophysics and intrusive investigation.
5. Excavation and restoration.

11.1.3. The remainder of this section contains descriptions of the alternatives and a description of the screening criteria.

11.2. ALTERNATIVE DESCRIPTIONS

11.2.1. Alternative 1: NDAI

The NDAI alternative means that remedial action will not be implemented to reduce the potential safety risk posed by suspect CAIS. This alternative, if implemented, would involve the continued use of the site in its current condition. If the potential exposure to CAIS and hazards associated with CAIS are compatible with the current conditions and future use of the site, then the implementation of NDAI would be warranted.

11.2.2. Alternative 2: Access Controls

11.2.2.1. Access controls are a form of land use controls (LUCs) that limit future receptor usage of the site by implementing various restrictions or dedicating the property to compatible use. Access controls can take the forms of signage, fencing, and land-use restrictions or regulatory control.

11.2.2.2. Signage describes a comprehensive sign posting system that entry to a site is prohibited, that activities within the property are restricted, that the area has a history of past CAIS-related activity, or a combination of this information. The signs are generally posted at the perimeter of the site and at key access points. Installation of the signs requires permission from the land owners and requires periodic repair or replacement of the signs.

11.2.2.3. Fencing provides a physical barrier to inadvertent future receptor entry. Enforcement of trespass restrictions will be more effective if fencing is present. The construction and maintenance of fencing can be recommended for specific sites, both as a feature for beneficial economic purposes and also as an enforcement tool to deny public access to areas designated as off-limits. As with signage, fencing will also reinforce the link between appropriate access and safety. Installation of fencing will also require permission from the land owners.

11.2.2.4. Legally enforceable land use restrictions and regulatory controls would dictate the type of development that will occur on a site and the methods in which that development occurs. Restrictive covenants and site plan requirements could be included in updates of county and regional comprehensive plans, as applicable.

11.2.2.5. Recurring reviews, as outlined in Section 121(c) of CERCLA, as amended by SARA, and Section 300.430 (f) (ii) of the NCP, are required for sites (at least every five years) where hazardous substances, pollutants, or contaminants remain at a site above levels that allow for unlimited use and unrestricted exposure following the completion of remedial actions. Recurring reviews will be conducted to 1) ensure that public health, safety, and the environment are being protected by the response actions implemented; 2) verify the integrity of any site controls; 3) determine if new information has become available that may warrant further action; 4) determine if there is an immediate threat to the public or environment that may require an Accelerated Response;

and 5) review decision for Technical Impracticability to determine if new technology will address potential CWM safety risk.

11.2.2.6. Data gathered during the review process will be used to determine if further action needs to be taken to protect public safety and the human environment. If no changes have taken place, the site will continue to be monitored at the specified intervals. At the completion of the review, a Recurring Review Report will be prepared and a public notice will be placed in the local newspaper concerning the continued effectiveness of the remedial action.

11.2.3. Alternative 3: Educational Awareness and Training

11.2.3.1. LUCs are measures undertaken to limit public exposure to CAIS potentially remaining at a site. These preventive measures may include educational awareness and training programs that have the goal of modifying behavior to reduce the risk of exposure and reduce the impact in the event exposure occurs. An educational awareness and training program will consist of development of generic educational tools and materials. Training materials will be made available through a public-access website. The frequency of the training will be up to the local stakeholders.

11.2.3.2. Training materials in the form of fact sheets, presentations, and videos have been prepared. The materials contain information on CAIS, history of chemical warfare, and the response process. The USACE District office will notify stakeholders and landowners as to the history of the site and location of the generic educational awareness and training materials by means of a fact sheet. The training materials have been posted to a public-access website at:

https://www.denix.osd.mil/denix/Public/Library/Explosives/UXOSafety/uxosafety.html.

Included in the video section of the website is the video entitled "*Chemical Warfare Materiel Training*", which includes specific information regarding CAIS. The narrative for this video is included as Appendix B.

11.2.3.3. Safety hazard educational awareness programs, such as the one proposed, can modify public behavior. Behavior modification is dependent upon the awareness and personal responsibility of the site user. If there is open access to the site, there is negligible risk to a potential receptor if the individual's behavior is appropriate for the site conditions. For behavior to be appropriate, one must understand the situation and voluntarily react in a responsible manner.

11.2.3.4. The educational awareness and training program will coincide with Project Closeout (PCO) and removal of the site from the project inventory for CWM. The PCO process will be conducted in accordance with ER-200-3-1 and will include regulator and public input with formal regulatory concurrence. The PCO materials will include information on accessing the educational awareness and training materials located on the public-access website. Although PCO may be selected and implemented for a site, if

CWM contamination or potential CWM items are found in the future, USACE will re-evaluate the site status and implement the appropriate response action.

11.2.4. Alternative 4: Geophysics and Intrusive Investigation

11.2.4.1. One method of potential CAIS hazard removal involves a combination of geophysical surveys and intrusive investigation of anomalies identified by the geophysical surveys. Under this alternative, metallic anomalies will be intrusively investigated until the anomaly is identified or until the site-specific risk-based specified depth is reached.

11.2.4.2. Prior to the intrusive removal activities at the site, control points will be established by a land surveyor for the areas that will undergo investigation. Brush clearing crews will clear sufficient undergrowth so that the digital geophysical mapping (DGM) crews can adequately perform their work. The brush clearance crews will be accompanied by UXO-qualified safety personnel.

11.2.4.3. Upon completion of land surveying and brush clearing, surface clearing will be conducted. The removal of surface clutter and metallic scrap, performed by experienced UXO-qualified personnel, will enhance the discrimination capability of DGM.

11.2.4.4. Once the surface clutter is removed, DGM of the site will be performed to map metallic anomalies located below ground surface. The DGM will be conducted with a metal detection device capable of locating metallic anomalies to the depth of clearance. The DGM data will be analyzed by a qualified geophysicist to identify subsurface metallic anomalies. Anomalies will be selected for intrusive investigation based on the assumption that CAIS ampoules and bottles will be contained in or adjacent to metallic packaging materials. Dig sheets will be created from these analyses to present the locations of subsurface metallic anomalies.

11.2.4.5. Locations of the metallic anomalies identified on the dig sheets will be reacquired using geophysical instruments and marked for intrusive investigation. The intrusive investigation would require that each anomaly location be excavated until the anomaly source is identified or until the predetermined clearance depth has been reached. In the event CAIS is found, soil samples will be collected to monitor for CAIS chemicals and breakdown products in the soil. When conducting intrusive excavation of anomalies potentially associated with CWM such as CAIS, special provisions for safety of workers and the public must be made, such as air monitoring for chemical releases using MINICAMS and DAAMS, establishment of an exclusion zone, use of a decontamination station, and keeping onsite medical support on standby. During the intrusive investigation, engineering controls may be used to decrease the size of the exclusion zone that will be required for conducting these intrusive investigations. Exclusion zones will be based on a reasonable worst-case scenario for the potential rupturing of a CAIS ampoule or bottle that could be found at the site. All non-essential personnel are evacuated based on this distance to maximize the safety of the operation. Metallic

objects obtained during the intrusive investigations will be identified as metallic scrap or CAIS-related items. In the event of finding CAIS, soil samples and, where appropriate, surface water samples will be collected and analyzed for CAIS chemicals and breakdown products.

11.2.4.6. Intrusive operations would require the development and approval of site-specific work plans including a Chemical Safety Submission (CSS) that details response actions and chemical agent monitoring. The site-specific work plans will also detail the sample handling, sample screening and shipping requirements associated with low level chemical agent contamination. Samples that exhibit the presence of chemical agents through headspace screening will not be transported off-site for additional analysis.

11.2.5. Alternative 5: Excavation and Restoration

11.2.5.1. Excavation and restoration involves excavation to remove CAIS from all potential burial areas at the site. The excavation depth for this alternative evaluation will be six feet based on CAIS disposal depths observed at other sites. If the excavation has reached six feet and there are indications that additional or potential CAIS items may be present at greater depths (i.e., magnetic locator indicates the presence of metal, encountered CAIS packing materials), the excavation will continue until the area has been cleared. Under this alternative, all existing vegetation, including tree cover, will be cleared to facilitate excavating site soils. Typically, no geophysical survey will be performed for this alternative. All excavated soils will be sifted to identify CAIS ampoules and bottles for proper disposal. Similar to Alternative 4, special provisions for the safety of workers and the public must be made, such as air monitoring for chemical releases using MINICAMS and DAAMS, establishment of an exclusion zone, use of a decontamination station, and keeping onsite medical support on standby. In the event CAIS is found, soil sampling will be conducted to determine if CAIS chemicals and breakdown products remain in the soil. Soils free of CAIS chemicals will be reused at the site for backfilling the excavations. Similar to the DGM and intrusive investigation alternative, a work plan and a CSS will also be required for this alternative.

11.2.5.2. The selection of this alternative could potentially lead to extensive site restoration activities following the removal action. Investigation areas could range in size from a small chemical storage area consisting of a few acres to a chemical warfare training area encompassing tens or hundreds of acres. If no suspect burial areas are known within the investigation area and the entire site has to be excavated, at a minimum, land use controls identifying the potential for CAIS to exist at a depth or depths greater than those excavated during the removal action must be implemented. If a site is partially excavated, land use controls should be implemented as stated above for the excavation area and for the remainder of the investigation area where no excavations were performed.

11.3. APPLICATION OF SCREENING CRITERIA BY ALTERNATIVE

11.3.1. This section discusses the performance of the five response action alternatives described in Section 11.2 relative to identified screening criteria. The screening criteria include:

- **Effectiveness** – the degree to which an alternative reduces the toxicity, mobility, or volume through treatment, minimizes residual risks, and affords long-term protection.
- **Implementability** – the technical and administrative feasibility of implementing the alternative.
- **Cost** – the costs of construction and any long-term costs to operate and maintain.
- **Reduction of Toxicity, Mobility, or Volume Through Treatment** – this evaluation criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal element.

11.3.2. Alternatives that meet these screening criteria will be carried forward for further evaluation in Section 12. The response action alternative evaluation presented in Section 12 will compare additional criteria for each of the alternatives. Section 12 presents the preferred alternative to reduce safety risk for each of the evaluated and qualified sites. The preferred alternative shall be the most practicable permanent solution as determined by the criteria specified in NCP (40 CFR 300.430).

11.3.3. NDAI **(Alternative 1)** does not provide protection to human health and environment, as it does not implement any remedial action to reduce potential risk. Current risk associated with CAIS has not been identified at these sites; however, there is the possibility of future risk being identified in association with intrusive activities. Implementation of this alternative does not meet the effectiveness screening criteria. Although, this alternative does not meet the screening requirements, it will be retained for further evaluation in Section 12 for comparative purposes.

11.3.4. **Access Controls (Alternative 2)** will meet the minimum threshold requirements for future use. Access controls, such as fencing and signage, will restrict access and minimize possible receptor interaction thus reducing the potential for exposure pathway completion. This alternative is not effective in terms of reducing toxicity, mobility, and volume through treatment; however, no burial or disposal sites have been identified at sites applicable to this Programmatic RI/FS. Fencing and signage is somewhat effective in reducing access to an area but is dependent on the cooperation of landowners for implementation and may prove too costly and too restrictive. Because CAIS locations are unknown, the entire site consisting of hundreds to thousands of acres would require fencing and signage. Also, the installation of fencing and signage may not coincide with current and planned land use. The cost for implementing fencing and signage is presented in Section 12 of this document and is based on quotes received for

similar efforts. This cost assumes readily accessible terrain in locations with moderate climate. In some locations, the cost is expected to be higher due to vehicular limitations and adverse terrain and climate. If these conditions are present, costs can be expected to increase by a multiplier of approximately 1.5. The cost for signs is presented on a per-sign basis with additional costs for installation. Maintenance costs for signs are also included as the signs will have to be maintained and replaced occasionally as they fade or are vandalized. Implementation of access controls are technically and administratively feasible and the services and materials necessary to implement such are readily available. Although costs may be excessive, access controls are retained for further evaluation based on their ability to inform the public of potential hazards and implementability criteria.

11.3.5. **Educational Awareness and Training (Alternative 3)** meets the effectiveness, implementability, and cost criteria but does not reduce the toxicity, mobility or volume of potential CAIS contamination through treatment. Providing the public with information on past site-related activities and increasing public awareness can effectively modify behavior for persons accessing the site. The implementation of Educational Awareness and Training will provide a temporary measure to mitigate potential risks to the public health and environment. Topics covered by Educational Awareness and Training will include: how to identify CAIS, potential hazards from CAIS, and the steps to be taken and authorities to contact if a CAIS item is found. Implementation of this alternative will provide long-term effectiveness through the process of recurring reviews. A review frequency of two years is recommended based on the estimated turnover rate for emergency responders and elected officials. The implementation of the training is dependent on the stakeholders. The USACE will not conduct the training. Training materials will be maintained on a public-access website:

https://www.denix.osd.mil/denix/Public/Library/Explosives/UXOSafety/uxosafety.html.

In addition, training of local responders can assure appropriate emergency response if CAIS are encountered. This alternative can readily be implemented in conjunction with the development of the PIPs. Costs for implementing the Educational Awareness and Training alternative are presented in Section 12 of this document. The costs for this alternative include the preparation and update of a PIP for the RI/FS phase. Following PCO, no additional costs are assumed. Educational awareness and training will be retained for further evaluation based on the attainability of the effectiveness, implementability, and cost screening requirements. Although the reduction of toxicity, mobility and volume criteria is not met, no identified burial or disposal locations of CAIS have been identified at sites covered by this Programmatic RI/FS.

11.3.6. **Geophysics and Intrusive Investigation (Alternative 4)** will be effective in identifying and removing subsurface metallic anomalies. Assuming CAIS are discovered as a result of the investigation of metallic anomalies, there will be some reduction in toxicity, mobility, and volume of CAIS through the removal of CAIS items and associated contaminated soils, if present. The current DGM technology can be

implemented and is readily used at numerous munitions response sites. This alternative, however, is ineffective at locating glassware. Although the level of risk may be reduced, the level of protection provided by implementing this alternative may not be adequate. In addition, because burial locations are unknown, the cost can be excessive if an entire site must be mapped and investigated. The costs for conducting a geophysical and intrusive investigation are presented in Section 12 of this document. Costs are presented on a per activity basis. The total cost of a geophysical and intrusive investigation will vary depending on the size of the site and the site conditions encountered. This alternative will be retained for further evaluation because it is effective at locating CAIS where metallic anomalies are present, although it does not completely remove the hazard.

11.3.7. **Excavation and Restoration (Alternative 5)** will involve excavation of all the site soils to a predetermined depth (such as six feet) below ground surface. As stated previously, excavation to depths greater than the predetermined depth could occur if there are indications that additional CAIS or potential CAIS items are located below the predetermined depth. To facilitate the excavation of site soils, all vegetation, including trees, will be removed. Excavated soils will be sifted to identify and remove CAIS-related items. Soils free from CAIS chemical contamination will be replaced into the excavated areas. Upon completion of backfilling, these areas will be re-vegetated and restored to their original condition. Implementation of the excavation and restoration alternative will be effective in reducing the toxicity, mobility, and volume of potential contamination through the removal of the source (CAIS) and associated contaminated soils, if present. Response standards will be achieved by implementing this alternative at the site. However, costs would be excessive and extensive site restoration would be necessary. The costs for implementing this alternative are presented in Section 12 of this document. Costs for the intrusive investigation are presented on a per-acre basis and are based on an aggressive figure of removing and sifting 500 cubic yards per week. A lower weekly intrusive investigation cost was also used on the assumption that work would progress in the same general area for extended periods. This alternative has been applied to small areas of some sites, for instance, Santa Rosa AAF, where it proved ineffective since additional burials were found outside the area of soil excavation. Despite the high cost, this alternative will be retained for further evaluation as a remedial action alternative.

SECTION 12
COMPARATIVE ANALYSIS OF ALTERNATIVES

12.1. INTRODUCTION

12.1.1. Five response action alternatives were evaluated against the screening criteria of (i) effectiveness; (ii) implementability; (iii) cost; and (iv) reduction of toxicity, mobility, or volume through treatment. Although not all of the identified alternatives met all of the screening criteria, the cleanup action alternatives identified for detailed analysis included NDAI, Access Controls, Educational Awareness and Training, Geophysics and Intrusive Investigation, and Excavation and Restoration.

12.1.2. This section presents the detailed analysis of these five remedial action alternatives to identify the preferred alternative for sites where CAIS is the sole type of potential CWM. The analysis consists of an assessment of each alternative against seven evaluation criteria and a comparative analysis.

12.2. EVALUATION CRITERIA

12.2.1. Overview

12.2.1.1. Remedial action alternatives are compared and evaluated with respect to seven evaluation criteria developed to address the statutory requirements and preferences of CERCLA. The seven criteria include:

1. Overall protection of human health and the environment.
2. Compliance with applicable or relevant and appropriate requirements (ARARs).
3. Long-term effectiveness and permanence.
4. Reduction of toxicity, mobility, or volume.
5. Short-term effectiveness.
6. Implementability.
7. Cost.

Two additional criteria, State Acceptance and Community Acceptance, will be evaluated at the FS phase for the state and the Proposed Plan phase for the community.

12.2.1.2. Each of the five alternatives are analyzed individually against each criterion and then compared against one another to determine their respective strengths

and weaknesses and to identify the key trade-offs. The alternative(s) identified as the most practicable solution in reducing the CAIS exposure hazard at the site was selected with respect to each evaluation criteria. The following sections provide a description of each of the seven criteria and the evaluation process used for performing the analysis.

12.2.2. Overall Protection of Human Health and the Environment

12.2.2.1. The overall protectiveness to human health and the environment was evaluated based on the impact each remedial action alternative has on the factors of possible CAIS exposure hazard. As discussed in Section 6, the CAIS exposure hazard is comprised of two components; the CAIS source characteristics and receptor interaction. Both of these two components (i.e., source and receptor) are required in order to pose a safety threat to the public.

12.2.2.2. The "protectiveness" criterion was evaluated in terms of possible future human interaction with CAIS chemicals, whether in containers or released to the environment. By definition, none of the sites have current CAIS-related risk since no known burial sites have been identified. An environmental protectiveness factor was included in the evaluation based on the protection employing an alternative will have on the existing environment and ecology. Each alternative was evaluated in terms of whether it would reduce the amount of CAIS chemicals currently in the environment. Alternatives 1 and 3, provide no protection since they do no remove any of the chemicals. Alternative 2 provides limited protection by reducing the accessibility. Alternative 4 has the potential to remove some of the chemicals but there will be no way to be sure all are removed. Alternative 5 has the potential to remove CAIS; however there will be no way to be sure all CAIS have been removed.. Both Alternatives 4 and 5 have a potential to cause an accidental release as part of the investigative or removal process. In terms of overall protection of human health and the environment, Alternative 5 was determined to provide the most protection.

12.2.3. Compliance with ARARs

No evaluation of remedial action alternatives with respect to ARARs has been performed since ARARs will be identified on a site-specific basis when implementing the Programmatic RI/FS. When implementing the Programmatic RI/FS for a particular site, compliance of the selected remedial alternative with site-specific ARARs must be verified. Non-compliance may indicate that the Programmatic RI/FS may not be applicable.

12.2.4. Long-Term Effectiveness and Permanence

The "permanence" criterion evaluates the degree to which a remedial action alternative permanently reduces or eliminates the potential for CAIS exposure hazard. Alternative 5 (Excavation and Restoration) was determined to provide the best long-term effectiveness and permanence based on the ability to remove the risk due to possible CAIS.

12.2.5. Reduction of Toxicity, Mobility or Volume through Treatment

This criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated media. Alternatives 1, 2, and 3 offer no reduction in toxicity, mobility, or volume of contaminants and were assigned with the lowest ranking. Alternative 4 provides some reduction of risk assuming that CAIS associated with metallic items are recovered during the intrusive investigation. Though CAIS may be located during the implementation of Alternative 4, individual glass CAIS could remain due to the inability to detect buried glass. Alternative 5 was determined to provide the greatest reduction of toxicity, mobility or volume through treatment as a result of excavating and sifting all suspect burial areas on the entire site. However, individual glass CAIS could remain elsewhere on the site. Implementation of this alternative would remove the source (CAIS) and associated contaminated soils to a predetermined target depth or to greater depths if there are indicated.

12.2.6. Short-Term Effectiveness

This criterion addresses short-term risks and the potential consequences and effects of an alternative during the implementation phase. Short-term risks address adverse impacts to the workers and community during the construction and implementation phases of the remedial action. Alternatives 5 was determined to have the greatest risk and least short-term effectiveness due to the risk to workers conducting deep excavation and sifting operations while using heavy equipment. Similarly, Alternative 4 has risks due to vegetation clearance requirements and the inherent risk during intrusive operations. Alternative 1 (NDAI) and Alternative 3 (Educational Awareness and Training) both present no short-term impacts or adverse impacts to workers and the community.

12.2.7. Implementability

The “implementability” criterion evaluates the technical and administrative difficulty of implementing a specific remedial action alternative. The evaluation included consideration of whether the alternative is technically possible; availability of necessary on-site and off-site facilities, services, and materials; administrative and regulatory requirements; and monitoring requirements. The NDAI (Alternative 1) and Educational Awareness and Training (Alternative 3) alternatives were determined to be the easiest to implement. The NDAI alternative is both technically and administratively feasible and no services or materials are necessary for implementation. Educational Awareness and Training is also both technically and administratively feasible with educational and training materials readily available through the USACE public-access website. Access Control (Alternative 2) is both technically and administratively feasible but would require landowner permission and potentially large amounts of materials to fence hundreds to

thousands of acres. Alternative 4 is not technically feasible since geophysical equipment cannot locate glass bottles and ampoules, unless co-located with metal. Alternative 5 is both technically and administratively feasible but requires specialized personnel and equipment to implement. These alternatives also require the development of detailed work plans. If there is a significant risk of encountering CAIS containing neat agent , a chemical safety submission and Department of Defense Explosives Safety Board (DDESB) approval will be required for Alternatives 4 and 5.

12.2.8. Cost

12.2.8.1. The "cost" criterion evaluates the financial cost to implement the remedial action alternative. The cost criterion includes direct, indirect, and long-term operation and maintenance costs. Direct costs are considered to be those costs associated with the implementation of the alternative. Indirect costs are those costs associated with administration, oversight, and contingencies. Cost estimates for each alternative are presented in Table 12.1. These costs were adapted from cost estimates prepared for the CWM Scoping and Security Study Report.

12.2.8.2. The actual costs will depend upon true labor rates, actual site conditions (e.g., number of anomalies, terrain, etc.), final project scope and other variable factors. The Alternatives with the lowest cost to implement would be Alternative 1 (NDAI) and Alternative 3 (Educational Awareness and Training). The NDAI alternative requires no action; therefore, no costs are incurred. Alternative 3 also requires no costs since the training materials are already available on the public access website. The remaining alternatives are all costly alternatives with Alternative 5 (Excavation and Restoration) the most costly to implement.

12.3. EVALUATION OF ALTERNATIVES

12.3.1. The five response action alternatives were evaluated in terms of the seven criteria. Table 12.2 presents a summary of the evaluation and identifies the most practicable solution for reducing the CAIS exposure hazard at a site. In some cases, more than one alternative was identified within the same evaluation category, indicating that those alternatives have similar compliance with the criterion.

12.3.2. The evaluation of the alternatives identified Alternative 1, Alternative 3, and Alternative 5 as the most practicable solutions for reducing the CAIS exposure hazard at a site. In addition to the evaluation of the alternatives, the screening criteria must also be considered. Alternative 1 – NDAI must be ruled out since it is ineffective in reducing the risk. Alternatives 2 and 5 both have high cost and are not implementable for any sites more than a few acres. Alternative 3 will partially reduce the risk by providing information to stakeholders and local responders. Alternative 4 will reduce the hazard due to CAIS remaining at the site only if they are associated with metal. Also, given the fact that the suspected CAIS sites consist of hundreds to thousands of acres, the cost of investigation of the complete site area would be prohibitive. Investigation of a reduced area may be more cost effective; however, the risk due to isolated CAIS bottles and

ampoules would remain. Therefore, Alternate 3 is the best alternative based on cost, effectiveness, and implementability.

12.4. RECOMMENDED ALTERNATIVE

An Educational Awareness and Training program with CWM Project Closeout is the recommended alternative for all sites categorized as suspect CWM sites that have CAIS as the sole remaining potential CWM hazard, including sites where a removal action has been completed. A description of the training program and PCO process is provided in Chapter 11.

Table 12.1
Estimated Costs Per Alternative

Alternative 1 - No Further Action

No cost associated with this alternative.

Total Cost Alternative 1: $0

Alternative 2 - Access Controls

Fencing	$5 per linear foot - installed
Signs	$75 each
	$15 installation cost per sign
	$20 annual maintenance per sign

Total Cost Alternative 2: Will vary depending on the size of the site(s)

Alternative 3 - Education Awareness and Training

Training	No site-specific cost
Follow-up Training	No site-specific cost
Public Involvement Plan (PIP)	$21,600 Initial cost
PIP Updates	$10,000 every 2 years until PCO completed

Total Cost Alternative 3: $121,600 if PIP updates occur for 20 years.

Alternative 4 - Geophysics and Intrusive Investigation

Work Plan	$66,000
Chemical Safety Submission	$30,600
Public Meeting	$51,600
Brush Clearing Mob/Demob	$14,700
Brush Clearing (10 acres)	$20,400
Geophysics Mob/Demob	$18,000
Geophysics (10 acres)	$21,500
Intrusive Investigation Mob/Demob	$83,000
Set-Up	$153,000
Pre-Operational Exercises (week)	$135,000
Intusive Investigation (week)	$117,000
Sample Analysis (20 samples)	$63,300

Total Cost Alternative 4: Will vary depending on the size of each site and site conditions.

Alternative 5 - Excavation and Restoration

Work Plan	$66,000
Chemical Safety Submission	$30,600
Public Meeting	$51,600
Brush Clearing Mob/Demob	$14,700
Brush Clearing (10 acres)	$20,400
Intrusive Investigation Mob/Demob	$83,000
Set-Up	$153,000
Pre-Operational Exercises (week)	$135,000
Intrusive Investigation (acre)	1,940,000(1)
Sample Analysis (20 samples)	$63,000

(1) Intrusive investigation cost is based on an aggressive figure of removing and sifting 500 cubic yards per week at a conservative weekly cost of $100,000 per week.

Note: the costs in this table include both contractors and Army agencies.

Table 12-2
Evaluation of Response Alternatives

Criteria	No Further Action Alternative 1	Access Control Alternative 2	Education Awareness & Training Alternative 3	Geophysics & Intrusive Alternative 4	Excavation & Restoration Alternative 5
Protectiveness	Least protective alternative. No source reduction. No reduction of risk associated with future intusive activities or surface manifestation resulting from erosion/frost heave.	No source reduction. Restricted access reduces interaction with CAIS, thus reducing risk. Possible for restrictions to be by-passed.	No source reduction. Hazard recognition to reduce chances of exposure. Training and education may not be effective for all persons..	Eliminates CAIS associated with metallic anomalies (if those anomalies are "picked"). Residual CAIS possible.	Most protective of human health; eliminates possible buried CAIS. Significant ecological damage.
ARARs Compliance	Not Evaluated	Not Evaluated	Not Evaluated	Not Evaluated	Not Evaluated
Effectiveness & Permanence	No CAIS-related risk reduction and no long-term effectiveness.	No reduction of possible CAIS, but can be effective at reducing possible receptor interaction. Access controls must be reviewed and updated/revised over time.	No reduction of possible CAIS, but can be effective at behaviour modification and appropriate response. Requires self-implementation by stakeholders.	Effective at identifying CAIS assocaited with selected metallic anomalies. Not effective at reducing CAIS-risk in areas without a metallic anomaly.	Removal of possible CAIS-related hazard. Highest degree of permanence.
Reduction of Toxicity	No reduction of possible toxicity.	No reduction of possible toxicity.	No reduction of possible toxicity	Reduction of toxicity for CAIS with metallic anomaly. Residual CAIS possible.	Greatest reduction of toxicity. Residual CAIS chemicals highly unlikely.
Short-term Effectiveness	No short term impacts to workers or community.	Possible short-term impacts associated with fence installation.	No short-term impacts associated with training and education	Risk associated with vegetation removal, heavy equipment, and possible interaction with CAIS.	Greatest short-term impacts to workers and community. Vegetation removal, use of heavy equipment, and possible interaction with CAIS.
Implementability	Readily implemented. No action required.	Signs and fencing to be installed. Land use controls require legal documentation. May not be compatible with intended land use.	General education and training material readily available. Requires notification of stakeholders	Requires qualified UXO technicians and geophysicists with specialized (but readily available equipment). Requires specialized air monitoring equipment and personnel (with limited availability). Requires work plans and CSS with DDESB approval.	Impractical, requiring and tying up limited specialized resources.
Cost	No cost.	No known burial locations; therefore, signage and fencing would be required for the entire property. Very costly alternative when long term maintenance is required.	No site-specific costs associated with training. Training materials are available on a public access website.	Very high initial costs associated with work plan and CSS development. The number of intrusive investigations is based on how anomalies are selected. Expensive to survey and investigate an entire site.	Prohibitive cost associated with this alternative. Could be much greater than $100,000 per acre. Since locations are unknown, many acres must be excavated.

Note: Shaded box indicates the most practicable solution in reducing the CAIS exposure hazard at a site.

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APPENDIX A

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY OF THE ARMY
INSTALLATIONS AND ENVIRONMENT
110 ARMY PENTAGON
WASHINGTON DC 20310-0110

APR 24 2007

SAIE-ESOH

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Treatment of Chemical Agent Identification Sets as Hazardous Waste

1. Effective April 23, 2007, the September 5, 1997, Interim Guidance for Biological Warfare Material (BWM) and Non-stockpiled Chemical Warfare Material (CWM) Response Activities, as amended, is changed (enclosure) to allow chemical agent identification sets (CAIS) that contain dilute chemical agents (CA) or industrial chemicals to be treated as hazardous waste, the exception is CAIS that may contain dilute nerve agent. Once determined to contain dilute chemical agents or industrial chemicals, CAIS, with the exception of the CAIS containing dilute nerve agent or neat CA, are no longer considered chemical agent materiel or chemical warfare materiel for the purposes of storage, treatment, or disposal.

2. CAIS that contain neat CA (i.e., CAIS K941 and CAIS K942) and any CAIS found to contain dilute nerve agent will continue to be managed as chemical warfare material (CWM).

3. My point of contact is J. C. King, (703) 697-5564 or jc.king@us.army.mil.

Addison D. Davis, IV
Deputy Assistant Secretary of the Army
(Environment, Safety, and Occupational Health)

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Attachment: Change to 5 Sep 1997 Interim Guidance for Biological Warfare Materiel and Non-Stockpile Chemical Warfare Materiel Response Activities

Effective 19 April 2007, the below changes are made to the September 5, 1997, Interim Guidance for Biological Warfare Material (BWM) and Non-stockpiled Chemical Warfare Material (WCM) Response Activities, as amended.

Paragraph 1.b. is changed to read, "For the purposes of storage, treatment, or disposal, Chemical Agent Identification Sets (CAIS) that are determined to contain dilute chemical agents, with the exception of dilute nerve agent or neat CA, or industrial chemicals are not considered chemical agent materiel or CWM. As such, CAIS that do not contain dilute nerve or neat chemical agent may be stored, treated and disposed of as hazardous waste. Procedures for handling chemical agent-contaminated media and CAIS will comply with DoD Ammunition and Explosives Safety Standards and Army regulations, and be treated per applicable federal, state, local laws. In addition, a certificate of destruction will be obtained from the permitted Treatment, Storage, and Disposal Facilities (TSDF) to which CAIS are transported for destruction."

Appendix B, Definitions, the definition of Chemical Warfare Material is changed to, "Chemical Warfare Material (CWM). Items generally configured as a munition containing a chemical compound that is intended to kill, seriously injure, or incapacitate a person through its physiological effects. CWM includes V- and G-series nerve agents or H-series (mustard) and L-series (lewisite) blister agents in other-than-munition configurations; and certain industrial chemicals (e.g., Hydrogen Cyanide (AC), Cyanogen Chloride (CK), or Carbonyl Dichloride (called phosgene or CG)) configured as a military munition. Due to their hazards, prevalence, and military-unique application, CAIS are also considered CWM. CWM does not include: riot control devices; chemical defoliants and herbicides; industrial chemicals (e.g., AC, CK, or CG) not configured as a munition; smoke and other obscuration producing items; flame and incendiary producing items; or soil, water, debris or other media contaminated with low concentrations of chemical agents where no CA hazards exist."

APPENDIX B

Appendix B
Example Conceptual Site Model – Programmatic RI/FS for Possible CAIS Sites

Subsite/Range	Acreage*	Suspect Past DoD Activities	Potential MD/MEC/CWM Presence	MD/MEC/CWM Found Since Closure	Previous Investigation-Clearance Actions/ Development	Post-DoD Land Use and Current Land Use	Potential Receptor	Potential MEC/CWM Source and Receptor Interaction	Potential MC Exposure Pathway	Field Sampling/ Qualitative Reconnaissance
ABC Army Airfield	2,500	Chemical warfare agent identification training using CAIS	None confirmed	None	Inventory Project Report, Archives Search Report	Agriculture, pasture, industry, residential	Human workers	No CAIS have been identified at the site but there is the possibility that CAIS remain; therefore, there is a potential interaction between CAIS chemicals and the receptor.	Potential acute exposure to vapors due to broken CAIS ampoules; potential dermal contact with CAIS chemicals; potential dermal contact with contaminated soil as a result of broken CAIS ampoules; potential exposure resulting from dermal contact with personnel contaminated with CAIS chemicals.	No CAIS disposal or burial areas have been identified; therefore, no sampling, reconnaissance, or intrusive investigation has been conducted.
*The acreage number presented includes the entire FUDS area comprising the former ABC Army Airfield. Since no disposal or burial areas have been identified, the potential exists for CAIS burial or disposal anywhere within the FUDS boundary.			CAIS = Chemical Agent Identification Set CWM = Chemical Warfare Materiel MD = Munitions debris MEC = Munitions and explosives of concern			DoD = Department of Defense				

APPENDIX C

Narrative from the Chemical Warfare Identification Training Video

Between World War I and World War II, military sites all over the United States engaged in training exercises using chemical warfare materiel for training troops in the use of protective clothing, decontamination, and agent identification.

Following the end of WWII, the remaining chemical warfare materiel was either used during training, retrieved and returned to a major storage point, or another accepted practice was burial of the material, as a last resort.

Today, many installations the military once used for training have been turned over to the public. These Formerly Used Defense Sites have been developed into residential areas, commercial airports, parks and farmland.

The U.S. Army Corps of Engineers in Huntsville, Alabama has made it a priority to evaluate all of the Formerly Used Defense Sites,
educate the public about their history, and raise safety awareness of chemical warfare material.

It is important for everyone to understand, that because of the development of these sites, chemical warfare materiel can be found **ANYWHERE**. So it is important to know what it looks like and what to do if you find it.

Chemical warfare materiel can be separated into three different types:

1) Bulk chemical agent
2) Munitions, and
3) Chemical Agent Identification Sets or CAIS.

Chemical agents were frequently stored in large quantities, or bulk. Bulk agent containers were used to fill smaller containers such as munitions. The two types of bulk containers that were typically used were:
Reinforced 55-gallon drums and 1-ton cylinders.

Chemical munitions were developed as delivery systems for chemical agents and were sometimes used to train solders for combat. They can be roughly grouped in the following categories:

- Grenades
- Rockets
- Mortars
- Artillery Shells
- Aerial Bombs and spray tanks, and
- Chemical mines and other items

In some cases the munitions hit the ground and did not explode. Just because a munition has been buried in the ground for several years does not mean it is not dangerous and won't explode.

So, if you find anything that you believe to be a chemical munition or a bulk container for chemical agent, it is important that you don't touch it and that you follow the proper safety steps, also known as the three "R's".

- **Recognize** you have discovered something that may be dangerous.
- **Retreat**, remember the location and immediately walk away from the area using the same path you came in on.
- **Report**, call 911.

Chemical Agent Identification Sets, commonly referred to as CAIS, consist of small quantities of chemical agents placed in glass vials or bottles. CAIS were packed in metal shipping containers or wooden boxes. CAIS can be found in the original shipping container or alone outside their original container.

In some cases vials or bottles will not be labeled, but if they are labeled they will most likely reflect only the chemical abbreviation.

The chemicals that were used in Chemical Agent Identification Sets include the following:

- Adamsite (DM)
- Chloroacetophenon (CN)
- Chloroform
- Chloropicrin (PS)
- Cyanogen Chloride (CK)
- GA Simulant
- Lewisite (L)
- Mustard (H, HD, HS)
- Phosgene (CG)
- Sarin (GB)
- Triphosgene

Some of the chemicals are still classified as chemical agents. All nerve kits containing Sarin (GB) and VX have been accounted for and destroyed.

Steel Cylinders, called pigs, were used to ship the vials or bottles of chemical agents. If you find something you believe to be a pig follow the three "R's".

Glass bottles or vials actually contained the chemical agent. These bottles or vials could be found empty or filled with chemical agent. It is important that you follow the three "R's" even if the bottles or vials are empty, so remember

- **Recognize** you have discovered something that may be dangerous.
- **Retreat**, remember the location and immediately walk away from the area using the same path you came in on, and
- **Report**, call 911.

If you believe you have been exposed to chemical agent it is important to seek immediate medical attention. If the proper safety measures are not exercised by the proper personnel, it can result in:

- Vomiting
- Burning eyes with excessive tearing
- Skin blisters
- And even death

Today, when the proper steps are taken and 911 is called, the proper military authority is notified, and the 20th Support Command is deployed. The chemical warfare material is then disposed of in safe and approved methods.

There have been cases of individuals bringing home these items as souvenirs as they are generally found in very good condition. As tempting as that may be it is never a good idea.

So always remember the three "R's". If you find something you believe to be chemical warfare materials or if you find something you cannot identify:

- **Recognize**
- **Retreat**
- **Report.**