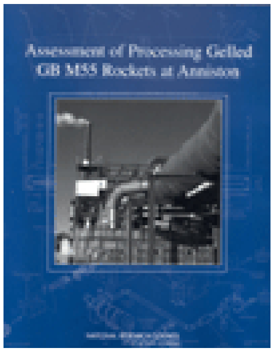

Assessment of Processing Gelled GB M55 Rockets at Anniston

Committee on Review of Army Planning for the Disposal of M55 Rockets at the Anniston Chemical Agent Disposal Facility, National Research Council

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Committee on Review of Army Planning for the Disposal of M55 Rockets
at the Anniston Chemical Agent Disposal Facility

Board on Army Science and Technology

Division on Engineering and Physical Sciences

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Preface

Since World War II, the United States has maintained a large stockpile of munitions containing chemical agents. In 1985, Congress mandated that the stockpile of M55 rockets containing agent be destroyed expeditiously because of the possibility they might self-ignite. The mandate was eventually expanded to cover the destruction of the entire stockpile of 31,495 tons of predominantly nerve and mustard agents located at nine sites, eight in the continental United States and one at Johnston Island in the Pacific Ocean southwest of Hawaii. The Army created the Chemical Stockpile Disposal Program to implement the destruction mission, and the office of the Program Manager for Chemical Demilitarization (PMCD) was established to manage it.[1] Congress also instructed the Army to seek the advice of outside independent authorities on the conduct of the program.

In response to this instruction, the Army requested the National Research Council (NRC) to advise it on stockpile destruction matters. The standing NRC Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (the Stockpile Committee) was established to provide this advice. Over the years, at the specific request of the Army, the NRC has produced 14 full reports and 16 letter reports on a wide variety of chemical demilitarization topics. The ad hoc Committee on Review of Army Planning for the Disposal of M55 Rockets at the Anniston Chemical Agent Disposal Facility (the M55 Committee) was formed under the purview of the Stockpile Committee to produce this report.

To date, approximately 26 percent of the total stockpile has been destroyed at two sites—Johnston Island in the Pacific Ocean and Tooele, Utah—using the Army's baseline incineration system technology. M55 rockets containing sarin (GB) nerve agent are among the munitions that were processed at both the Johnston Island and Tooele facilities. At Johnston Island, all of these rockets contained liquid agent that could be drained and processed in the liquid incinerator. The remainder of each rocket was chopped into pieces and processed in a rotary kiln called the deactivation furnace system (DFS). Most of the GB-filled M55 rockets at Tooele likewise contained liquid agent, but a significant number contained gelled or semisolidified agent that could not be drained. Gelled material varies in properties, with some of it showing only a modest increase in viscosity (molasses-like properties) and some being semisolid (like gelatin). When heated, the gel starts to melt and flow like a liquid again. A special processing sequence was developed that bypassed the draining station. Rockets containing gelled GB were chopped into pieces with the gelled agent inside, and the sheared segments were processed in the DFS. Regulatory requirements of the state of Utah required that the rate at which these rockets were processed be reduced such that the amount of agent being fed into the DFS be no greater

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[1] Early in 2003, activities were initiated for PMCD to be subsumed, along with the staffs of the Assembled Chemical Weapons Assessment (ACWA), the Project Manager for Alternative Technologies and Approaches (PMATA), and the chemical depots, into a new overarching organization, the Chemical Materials Agency. CMA will thus be responsible for both the storage and destruction of the U.S. stockpile of chemical agents and munitions. In this report, the earlier acronym, PMCD, will be used.

than the amount of residual agent (5 percent) allowed when drained rockets were processed. The Army believes that gelled GB rockets can be processed through the DFS at a substantially higher rate while still meeting the rigid requirements of a safe operation and accomplishing the required 99.9999 percent destruction of agent.

If the rockets at the Anniston site are processed faster, the risk to the public from the continued storage of the overall Anniston stockpile will be less. Risk assessments have consistently indicated that the risk to the public from ongoing storage is significantly higher than the risk from disposal processing. The Army therefore asked the NRC to evaluate the possibility that gelled rockets could be destroyed safely and effectively at a higher rate than at Tooele. A second, very similar request was received from then-Congressman Robert R. Riley of Alabama, now governor of the state.

The M55 Committee would like to recognize the assistance given by Army staff and contractors in providing information and answering questions from the committee. The committee is likewise grateful for the assistance of NRC staff members Donald L. Siebenaler, Harrison T. Pannella, Carter W. Ford, James C. Myska, William E. Campbell, and Elizabeth Fikre in producing this report.

James F. Mathis
Chair
Committee on Review of Army Planning for
the Disposal of M55 Rockets at the Anniston
Chemical Agent Disposal Facility

Acknowledgment

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Chadwick A. Tolman, University of Delaware

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Hyla S. Napadensky, Napadensky Energetics, Inc. (retired). Appointed by the NRC's Report Review Committee, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Acronyms

ACAMS	automatic continuous air monitoring system
ADEM	Alabama Department of Environmental Management
ANCDF	Anniston Chemical Agent Disposal Facility
ATB	agent trial burn
BRA	brine reduction area
Btu	British thermal unit
CAC	citizens advisory commission
CFD	computational fluid dynamics
CMA	Chemical Materials Agency
CR&E	Continental Research & Engineering
CSDP	Chemical Stockpile Disposal Program
CWDA	cases with days away (from work) per 200,000 hours worked
DFS	deactivation furnace system
DICDI	diisopropylcarbodiimide
DPE	demilitarization protective ensemble
DRE	destruction and removal efficiency
DUN	dunnage incinerator
ECR	explosion containment room
EPA	Environmental Protection Agency
GB	sarin, a nerve agent (methylphosphonofluoridate, isopropyl ester)
H	mustard (blister) agent, bis-(2-chloroethyl) sulfide
HCE	hexachloroethane
HCl	hydrogen chloride
HD	mustard (blister) agent (distilled)
HDC	heated discharge conveyor
HEPA	high-efficiency particulate air (filter)
HRA	health risk assessment
HT	mustard (blister) agent (with additive T, bis-[2(2-chloroethylthio) ethyl] ether, to lower the freezing point)
HTT	high-temperature test
JACADS	Johnston Atoll Chemical Agent Disposal System
LIC	liquid incinerator
LTT	low-temperature test
MCB	monochlorobenzene
MDB	munitions demilitarization building
µg	microgram, one one-millionth of a gram
µg/m^3	micrograms per cubic meter
mg/dscm	milligrams per dry standard cubic meter
mm	millimeter, one one-thousandth of a meter
MPF	metal parts furnace
MR&E	Maumee Research & Engineering
NC	nitrocellulose
NG	nitroglycerine
ng	nanogram, one one-billionth of a gram

ng/m^3	nanograms per cubic meter
NRC	National Research Council
ONC	on-site container
OVT	operational verification test
PAS	pollution abatement system
PCB	polychlorinated biphenyl
PFS	PAS filter system
PMCD	Program Manager for Chemical Demilitarization
PRO	preroundout GB agent
QRA	quantitative risk assessment
RCRA	Resource Conservation and Recovery Act
RD	distilled roundout GB agent
RHS	rocket handling system
RIR	recordable injury rate
RO	roundout GB agent
rpm	revolutions per minute
RS	GB agent lots restabilized with DICDI
RSM	rocket shear machine
SBCCOM	Soldier Biological and Chemical Command
SOPC	substances of potential concern
SOT	statement of task
TBA	tributylamine
TOCDF	Tooele Chemical Agent Disposal Facility
TSCA	Toxic Substances Control Act
VX	a nerve agent, O-ethyl-S-(2-isopropylaminoethyl) methyl phosphonothiolate

Executive Summary

There are 2,253 tons of chemical agents in the 661,559 individual munitions and 108 ton containers stored at Anniston Army Depot in Anniston, Alabama. This is almost 10 percent of the current 23,416 tons of mustard and nerve agents in the U.S. chemical weapons stockpile. The Anniston Chemical Agent Disposal Facility (ANCDF) has been constructed and is being readied for operation in 2003 with the mission of destroying the aging munitions and bulk containers of agent in this stockpile safely and expeditiously. The quantitative risk assessment (QRA) performed for Anniston indicates that the risk to the public is dominated by accidents that could arise from the storage of M55 rockets filled with GB nerve agent. The QRA suggests that as the M55 rockets are safely destroyed during the first disposal campaign, the risk to the public decreases.

During disposal of GB M55 rockets at Tooele, Utah, about 5,000 rockets could not be drained because the GB contents had gelled. These gelled rockets were processed at a much slower rate that required modification and extension of the disposal process. About 20 percent (at least 8,706) of the Anniston GB M55 rockets are now estimated to be gelled. The Army has developed modified plans for their safe and expeditious disposal. This report reviews those plans. The discussions in this report focus on technical considerations and related issues in going from a gelled GB M55 rocket processing rate of 1.0 or 1.6 rockets per hour to 9.2 rockets per hour, which would work out to 6.4 rockets per hour on the basis of an expected 70 percent availability for the deactivation furnace system (DFS). Other rates that are reported are given to reflect the variability of operational experience to date in the processing of both gelled and ungelled (drained) GB M55 rockets. Drained rockets are defined as rockets from which at least 95 percent of the agent has been removed.

The M55 Committee's formal findings and recommendations can been found in Chapter 5. Major points from the findings and recommendations have been incorporated into the narrative text of this Executive Summary, along with abbreviated background material.

THE BASELINE INCINERATION SYSTEM

As of July 2002, about 26 percent (8,082 tons) of the original 31,495-ton stockpile had already been destroyed in baseline incineration system facilities at Johnston Island in the Pacific Ocean and at Tooele, Utah. ANCDF, with minor changes, is patterned after those two facilities, the Johnston Atoll Chemical Agent Disposal System (JACADS) and the Tooele Chemical Agent Disposal Facility (TOCDF). In baseline facilities such as these, munitions are transported from the depot storage area to a receiving dock at the disposal facility, unloaded, and conveyed into explosive containment rooms, where they are disassembled by machines (or, in the case of rockets, sheared into sections) and drained of agent. The agent is disposed of in a liquid incinerator (LIC) furnace. The metal shell casings or ton container sections are decontaminated in a metal parts furnace (MPF). The energetics—burster charges, fuzes, and propellants—

are destroyed in a DFS, which is a rotating kiln. There was also a fourth furnace at JACADS and TOCDF, the dunnage incinerator (DUN), which was designed to destroy various nonmunition wastes such as shipping pallets. However, when ways were found to ship these wastes off-site or to destroy them in the MPF, the DUN was no longer required, so none has been included in the ANCDF design.

Each of the three furnaces in the ANCDF baseline design has its own pollution abatement system (PAS). In a PAS, the hot flue gas, containing some acidic products from agent combustion, is treated with caustic to form brine, filtered, and discharged through a stack. The brine can be either shipped off-site to a permitted disposal facility or treated in a brine reduction area (BRA). Again, because the Army has found that off-site disposal can be done safely and economically, the BRA at Anniston probably will not be used. A third difference from JACADS and TOCDF is that the exhaust gas that leaves a PAS at ANCDF is then passed through a filter system (high-efficiency particulate air [HEPA] and activated carbon) before being discharged through the stack. These HEPA and carbon filters, known as the PAS filter system (PFS), provide a second line of defense to ensure that agent, metals, and other potentially harmful products are not released to the environment.

M55 ROCKETS

Among the munitions stored at Anniston there are 42,738 GB M55 rockets and 24 GB M56 rocket warheads containing 10.7 lb of GB agent each. Another 35,636 rockets and 26 warheads contain 10 lb of VX nerve agent each. An explosive burster charge activated by an impact fuze disperses the agent when the rocket hits a target. M55 rockets are powered by a stabilized double-base propellant, nitrocellulose and nitroglycerin, which ignites when the rocket is fired. The rocket has an aerodynamically shaped, finned aluminum body that is contained and shipped ready to use in a fiberglass firing tube. Altogether, the combustibles in each rocket—agent, burster charge, fuze components, propellant, and epoxy resin in the fiberglass shipping tube—weigh about 40 lb.

GB M55 rockets carry the highest risk potential of any chemical stockpile munitions. This is in part because GB is more volatile than VX and can disperse farther in an accidental release, and in part because the rockets, which are arranged in compact arrays of 15 per pallet, are stored in igloos, as are most other items in the chemical stockpile. Thus, if one rocket were to ignite, it might ignite the others. While this is also true for rockets containing VX, which is more toxic than GB, VX is not as volatile and will not disperse as widely as GB. The net effect of this in terms of risk management is the scheduling of GB M55 rockets to be processed first. This is how the processing was managed for JACADS and TOCDF and how it is planned for ANCDF.

Storage Stability of GB M55 Rockets

Concerns about the storage stability of GB-filled rockets led Congress in 1985 to legislate destruction of the stockpile. Among the concerns was the fact that the propellants degrade slowly, possibly leading to autoignition. A stabilizer compound, 2-nitrodiphenylamine, had been added to the propellant during manufacture to scavenge products of the degradation reaction. However, once stabilizer concentrations fall below a critical level, there is some risk of a runaway reaction that could cause the propellant to autoignite. Enough stabilizer was therefore added to protect the rockets from autoignition over what was originally thought to be a safe storage period. The stockpile has been monitored in the interim, and rocket sampling studies show that the expected depletion of stabilizer continues.

Another concern was that GB munitions were found to leak at about five times the rate of other munitions (about 0.25 percent versus 0.05 percent). Leaking munitions, including rockets, generally have been overpacked in tightly sealed steel containers. Overpacking usually controls leaking but heightens concerns about autoignition because the container acts as a barrier to heat transfer from within the rocket to the surrounding air in the storage igloo. Also, if GB leaks into the propellant, there is a further possibility of accelerated propellant degradation.

Since 1985, a number of scientific evaluations have assessed the likelihood of autoignition over time, as the stockpile ages. All concluded that completion of stockpile destruction, currently programmed to meet the 2012 extended deadline of the international Chemical Weapons Convention treaty, will occur long before the risk of autoignition is appreciable, even for overpacked, leaking rockets. The frequency estimate for an M55 autoignition event in the latest study is site specific; currently, it is approximately 3×10^{-5}

per year for the Anniston site.[1] This is much lower (by a factor of 60) than the estimated 2×10^{-3} per year frequency (an average of once in 500 years) of ignition from a lightning strike on a storage igloo. According to the stability model used by the Army, the autoignition probability will increase gradually but will stay below the lightning strike probability measure until 2020. The M55 Committee has broadly reviewed the rationale, structure, and results of this study and concluded they are sound. A more detailed review will be presented in a forthcoming National Research Council report on the status of stockpile degradation.

Gelled GB M55 Rockets

GB and VX M55 rockets are normally processed by first draining at least 95 percent of the agent from a rocket, shearing it into sections in a rocket shear machine (RSM) in the explosion containment room (ECR) and processing the sections in the DFS kiln system. The drained agent (less a 5 percent or smaller heel of agent that usually remains in the rocket) is fed to the LIC. The MPF is not used in processing rockets. At JACADS, all the GB and VX rockets contained ungelled agent and were drained and processed in this manner, and most of the GB rockets processed at TOCDF were also processed this way. However, three particular lots in the Tooele stockpile totaling 5,287 GB rockets (of the 28,945 total) contained gelled agent that would not drain. Gelling is apparently the result of GB degradation, which increases acidity, leading to a reaction with the aluminum tank material. It is believed that this produces an aluminum phosphonate species that can, over time, link GB derivatives and cause them to gel. Most of the originally more acidic agent lots were restabilized with diisopropylcarbodiimide (DICDI), and some of the restabilized lots are those that are gelled. Most other remaining lots contain another agent stabilizer, tributylamine, and no gelling effects were detected when that stabilizer had been used.

At Anniston, the current estimate is that 8,706 of the 42,738 GB M55 rockets are probably gelled, based on munition lot numbers that have been associated with gelled agent. Very few gelled rockets are expected to be encountered at the other two sites using the baseline incineration system for disposal (Pine Bluff, Arkansas, and Umatilla, Oregon). For this reason, any gelled rockets at those two sites can be processed at the limited rate of 1.6 rockets per hour used at TOCDF without causing serious delays. The committee suggests the Army proceed at the Pine Bluff and Umatilla sites under existing permit applications, which (as in the case of TOCDF) provide for a processing rate in the DFS based on agent loadings from processing rockets with no more than a 5 percent agent heel.

Lessons Learned at JACADS and TOCDF in Rocket Processing Operations

The very first agent disposal operation undertaken in the Chemical Stockpile Disposal Program (CSDP) was the processing of drained (ungelled) GB M55 rockets at JACADS starting in 1989. The planned goal was 32 rockets per hour. A "best shift" rate achieved for one day was 27 rockets per hour during the first operational verification test (OVT 1) campaign. The best operation over an extended period (the "full rate") was 15.3 rockets per hour. The processing at JACADS represented first-time experience with an (at that time) untried, extremely complex process system. Much of the processing rate shortfall can be attributed to the learning that was necessary for the operations team, notwithstanding the months of training that had been invested before start-up. After some modifications to equipment and procedures as a result of problems encountered, the VX rocket operation (OVT 2) went more smoothly. The full rate was 20.6 per hour, although 32 rockets were processed per hour over one full 10-hour shift.

TOCDF benefited significantly from the JACADS experience, and operations there on ungelled rockets went well. However, the processing of gelled rockets caused serious delays. These rockets were processed in a substantially different way than the ungelled ones. In the ECR, gelled rockets bypassed the drain station and were sheared in the RSM into segments containing large amounts of agent as well as fiberglass and energetics. This mix of rocket components and agent was fed to the DFS kiln. Neither the LIC nor the MPF was used to process rockets in this instance. The total com-

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[1] This is the median site-specific annual autoignition probability for overpacked rockets at Anniston and is equivalent to about one chance in 33,000 per year. The median site-specific annual autoignition probability for nonoverpacked (undetected) leaking rockets at Anniston is approximately 1.4×10^{-6} (about one chance in 700,000 per year). The lower frequency estimate for nonoverpacked leaking rockets is due to their lower peak heat generation and slightly higher heat losses compared with overpacked rockets.

bustible content per rocket delivered to the DFS kiln thus went from roughly 30 lb to 40.4 lb. TOCDF management obtained approval from the Utah regulatory authorities for 1.6 gelled rockets to be processed through the DFS kiln each hour. This contrasts with the permit rate of 32 drained, ungelled rockets per hour. The rate for gelled rockets was reduced so that the same amount of agent would be destroyed per hour in the DFS as would have been the case when drained rockets with a 5 percent heel were processed. When downtime is taken into account, the actual average rate for processing gelled rockets over the entire campaign was approximately 0.6 rockets per hour.

To speed destruction of the entire inventory of GB munitions at the Deseret Chemical Depot at Tooele, TOCDF management developed the concept of "co-processing." While gelled rockets were being processed through the DFS, GB projectiles, reconfigured to remove the energetics, were coprocessed through the LIC and MPF. Utah regulatory authorities gave permission to do this if the gelled GB rocket processing rate was reduced further, to 1.0 rocket per hour.

The Army believes that gelled GB rockets could have been processed through the DFS system at TOCDF safely and effectively at a faster rate, but this was not demonstrated. The M55 Committee agrees with the Army's judgment and recommends that the Army pursue means to demonstrate the safety of a faster rate. Another way to process rockets and projectiles containing the same agent is called "complementary processing." In this variation, rockets are processed by themselves for a few days, and then projectiles are processed by themselves while maintenance is performed on the rocket processing equipment. Complementary processing was also tried successfully at TOCDF.

At both JACADS and TOCDF, mandatory trial burns were undertaken to test for agent destruction and removal efficiency (DRE) and for emission of metals or toxic substances such as dioxins and furans. The prescribed 99.9999 percent DRE for agent was met in all but one of the eight trial burn tests at JACADS. The temperature and residence time in the DFS afterburner were increased in the TOCDF (and ANCDF) design to ensure more complete combustion. In a few tests, mercury and lead emissions exceeded standards at both JACADS and TOCDF. A PFS is being employed at ANCDF to ensure compliance with the more stringent requirements that have since been instituted for control of emissions. Comprehensive measurements of nonagent emissions are made only during infrequent trial burns. This is in accord with standard industrial practice and regulatory requirements. As long as the furnace functions within normal operating limits, these emissions should not change. However, the M55 Committee believes that more frequent monitoring could reassure the public. The lack of similar data for regular operations makes it difficult to convince the public that emissions are always within permit limits.

DISPOSAL SCHEDULES FOR ANCDF

The ANCDF Original Plan

The first schedule for disposal operations at ANCDF called for processing in the following order:

- GB M55 rockets
- agent changeover
- VX M55 rockets
- VX munitions
- agent changeover
- GB munitions
- agent changeover
- HD/HT (mustard agent) ton containers and munitions

This schedule was developed before there was a recognition that gelled rockets would have to be processed. After gelled rockets were discovered at TOCDF and it became clear that there are many of them in the Anniston stockpile as well, the Army commissioned experienced furnace consultants who had worked on the baseline furnaces at JACADS and TOCDF to estimate the rate at which gelled GB rockets could be processed through the DFS system. The consultants constructed a mathematical model that was necessarily a simplification of the actual DFS kiln. Backed by some detailed modeling work, assumptions were made about how much of the GB, propellant, burster, fuze, and epoxy resin would burn at various points along the DFS kiln. Based on the modeling, the consultants concluded that the DFS kiln could safely process up to 34 gelled rockets per hour. They recommended, however, that this goal be approached gradually during the GB agent trial burn period.

The M55 Committee believes the 34 per hour rate is optimistic, but it supports the idea of ramping up production gradually, to a higher rate than was employed at TOCDF. Some of the committee's concerns about the 34 per hour rate are these: (1) the maximum rate of heat release at the inlet to the DFS may be higher than assumed in the model; (2) unless properly managed, the instantaneous rate of heat release may lead to temperature spikes and resultant pressure puffs that could release agent into the DFS room and/or the ECR; and (3) agent will probably melt and may then vaporize and undergo thermal decomposition and oxidation in the feed chute, since the chute would be hotter than in the TOCDF runs. This could require limiting the feed rate. Also, the current DFS instrumentation—the Process Data and Recording System—should be reconfigured and used during the ramp-up period of the agent trial burn to measure and record instantaneous peak gas temperatures, differential pressures, and feed chute metal temperatures.

In May 2002, ANCDF successfully conducted trial burns in the DFS kiln on gelled rocket surrogates (i.e., nonagent materials). The DREs were better than the 99.9999 percent permit limit, and emissions of metals, carbon monoxide, and other toxic materials were within limits when the PFS was in service. Levels of cadmium, lead, and mercury exceeded regulatory limits when the PFS was not in service during some of the surrogate trial burns, but it will be placed in service during agent operations. The surrogate trial burn demonstration, which fed combustibles through the DFS equivalent to the weight of combustibles in 15 gelled rockets per hour, suggests that a larger number of rockets containing gelled agent can be safely processed per hour than were processed at TOCDF.

The Army has derived another target rate for processing gelled rockets based on having only one rocket in the DFS kiln at a time. At the planned rotation rate of 1.85 rpm, it takes 6.5 min for solids to traverse the kiln length. This produces a rate of 60/6.5, or 9.2 gelled rockets per hour. This rate was used in both the original plan and the modified plan discussed below. It is probably achievable, but it should be approached gradually and with a fully instrumented DFS system. Using this rate, plus the normal rates for the other munitions, the Army has estimated it would take 7.2 years to process the entire Anniston stockpile (see Appendix B). As noted above, there would be three agent changeovers. During agent changeover operations, all areas exposed to agent are decontaminated by workers in demilitarization protective ensemble (DPE) suits. Since the monitors are agent specific, once the area is cleaned so that the previous agent is nondetectable, they are replaced with instruments calibrated for the agent that will be processed in the next campaign. Changeover operations are labor intensive and typically take about 4 months.

The ANCDF Modified Plan

Based on the successful experience at TOCDF in coprocessing GB rockets and other munitions, the Army developed a modified plan for ANCDF. In this plan, GB munitions are processed in a complementary manner with GB rockets, gelled or ungelled (see the description of complementary and coprocessing in Chapter 3). The gelled rockets are processed at the rate of 9.2 per hour as in the original plan, and the drained ungelled rockets are processed at a rate as high as 32 per hour. The processing sequence in the modified plan is as follows:

- complementary and coprocessing of GB rockets and munitions
- agent changeover
- VX rockets
- VX munitions
- agent changeover
- HD/HT ton containers and munitions

This schedule is estimated to take 6.3 years to complete, 10 months fewer than the original schedule. If gelled rockets are processed at the rate of 1.6 per hour, demonstrated at TOCDF, complete destruction of the ANCDF stockpile is estimated to take 7.6 years (see Appendix B). Although the modified plan would thus provide more expeditious elimination of the storage risk from the overall Anniston stockpile, local officials and members of the public have questioned the safety of processing gelled rockets at a rate higher than that used at TOCDF.

Assessment of Public and Worker Risks Under the Two Plans

QRAs can be used to identify all conceivable accident sequences that might lead to a harmful release of agent. For each sequence, a frequency of occurrence and the potential impacts on public and worker safety are estimated. Overall risk estimates are computed by summing over all the individual sequences to give composite expected values of risk over the duration of the disposal program. QRAs are site specific since the population densities, terrain, weather patterns, and potential for natural disasters (earthquakes, lightning strikes, forest fires, etc.) are different at each site. The QRAs conducted for each site have consistently shown that the risk of accidental release of agent during storage is larger than the risk during processing. As noted earlier, different munition-agent combinations represent different levels of risk, with GB M55 rockets representing the highest risk.

Assuming a maximum processing rate of 9.2 gelled GB rockets per hour, the QRA estimate of the total risk to the public over the 7.2 years necessary to destroy the Anniston stockpile according to the original plan is 0.058 expected fatalities. Over the 6.3 years necessary for the modified plan, which processes gelled GB rockets at the same rate and coprocesses other GB munitions, the total risk is 0.065 expected fatalities. This is the estimated number of fatalities expected from start to completion of disposal processing. The total public risk level in the modified plan if the TOCDF rate of 1.6 rockets per hour is employed climbs to 0.095 expected fatalities for the 7.6 years necessary to destroy the entire Anniston stockpile. The slightly higher level in the modified plan results from keeping the VX rockets in storage an extra 4 months while the remainder of GB munitions is destroyed. The worker risk assessment has not been revised for these options, but it seems reasonable that the elimination of an extra agent changeover operation will reduce overall worker risk.

If the assumptions made in developing the risk estimates in the QRA are accepted and the inherent uncertainty surrounding such estimates and the trade-offs between public and worker risk are taken into account, it is not possible to differentiate meaningfully between the processing plan options based on calculated risk alone. The committee therefore recommends that the modified plan be undertaken with precautionary ramp-up of the production rate until a safe upper production limit is established or the maximum permitted rate is achieved.

The overall risk from the stockpile is increased by any programmatic delays, because the risks in storage increase with time and remain greater than the risks of disposal operations. Unresolved issues between the Army and the Chemical Stockpile Emergency Preparedness Program, as well as between the Army and regulatory groups, need to be addressed expeditiously. Further, it is important that the Army improve communications with the local communities, both to promote a better understanding of the risk issues and to address any valid public concerns. The health risk assessment (HRA) for ANCDF has not been completed because the agent trial burns have not been done. The HRA is concerned with exposures to possible toxic emissions other than agent, for example, metals and organic emissions such as dioxins and furans. The Army should complete the HRA for the ANCDF as soon as feasible. The fact that emissions in the surrogate trial burns were low suggests that the agent trial burns will meet relevant standards.

1

Introduction

CHEMICAL STOCKPILE DISPOSAL PROGRAM

The Army Chemical Stockpile Disposal Program (CSDP) was begun in 1985 as a result of the congressional mandate in Public Law 99-145 to dispose of the nation's aging chemical agent and munitions stockpile. CSDP activities are proceeding at the nine sites where portions of the stockpile have been stored. Disposal operations on Johnston Island, about 800 miles southwest of Hawaii, were completed in November 2000. The Johnston Atoll Chemical Agent Disposal System (JACADS), the first baseline incineration system disposal facility, became operational in 1990. By the completion date, the 2,031 tons of agents in 412,732 munitions in storage on Johnston Island had been destroyed (NRC, 2002a).

Eight other stockpile storage sites are located in the continental United States. Operations at a second baseline incineration system disposal facility, the Tooele Chemical Agent Disposal Facility (TOCDF), in Tooele, Utah, are well under way. All 6,047 tons of nerve agent GB that were stored there in munitions and containers have been destroyed. Together, as of July 2002, JACADS and TOCDF had destroyed 25.6 percent of the original 31,495 tons of agent that were stored at all nine sites. Construction of three other baseline incineration system disposal facilities has been completed in Anniston, Alabama; Umatilla, Oregon; and Pine Bluff, Arkansas. Two other disposal facilities are nearing completion in Newport, Indiana, and Aberdeen, Maryland. Planning for the last two facilities, in Pueblo, Colorado, and Blue Grass, Kentucky, is in progress. The facilities in Maryland, Indiana, Colorado, and Kentucky will employ chemical neutralization (hydrolysis) instead of incineration as the primary means of agent destruction.

The overall stockpile consists of a variety of chemical agents and munitions. The chemical agents are primarily the nerve agents GB (sarin) and VX and mustard agent (H, HD, HT), which is a corrosive vesicant (blister) agent. The munitions consist of projectiles, mines, and rockets, all of which contain several pounds of agent each. There are also spray tanks, bombs, and ton containers, each containing hundreds of pounds of agent. The composition of the stockpile and the various munitions has already been documented (NRC, 1994a).

M55 ROCKET PROCESSING

M55 rockets filled with GB constitute the most hazardous munition-agent combination in the stockpile because GB is the most volatile agent. An M55 rocket is depicted in Figure 1-1. Because of concerns about the higher risks of continued storage of M55 rockets containing either GB or VX, the Army's plans for disposal at the sites where the M55 rockets are stored have always scheduled their processing early in the agent disposal campaigns. There is an incentive to process the rockets as soon as safely possible since this reduces the storage risk faster. The rate at which rockets can be processed is a function of both the facility design capacity and the rate allowed in the Resource Conservation and Recovery Act (RCRA) op-

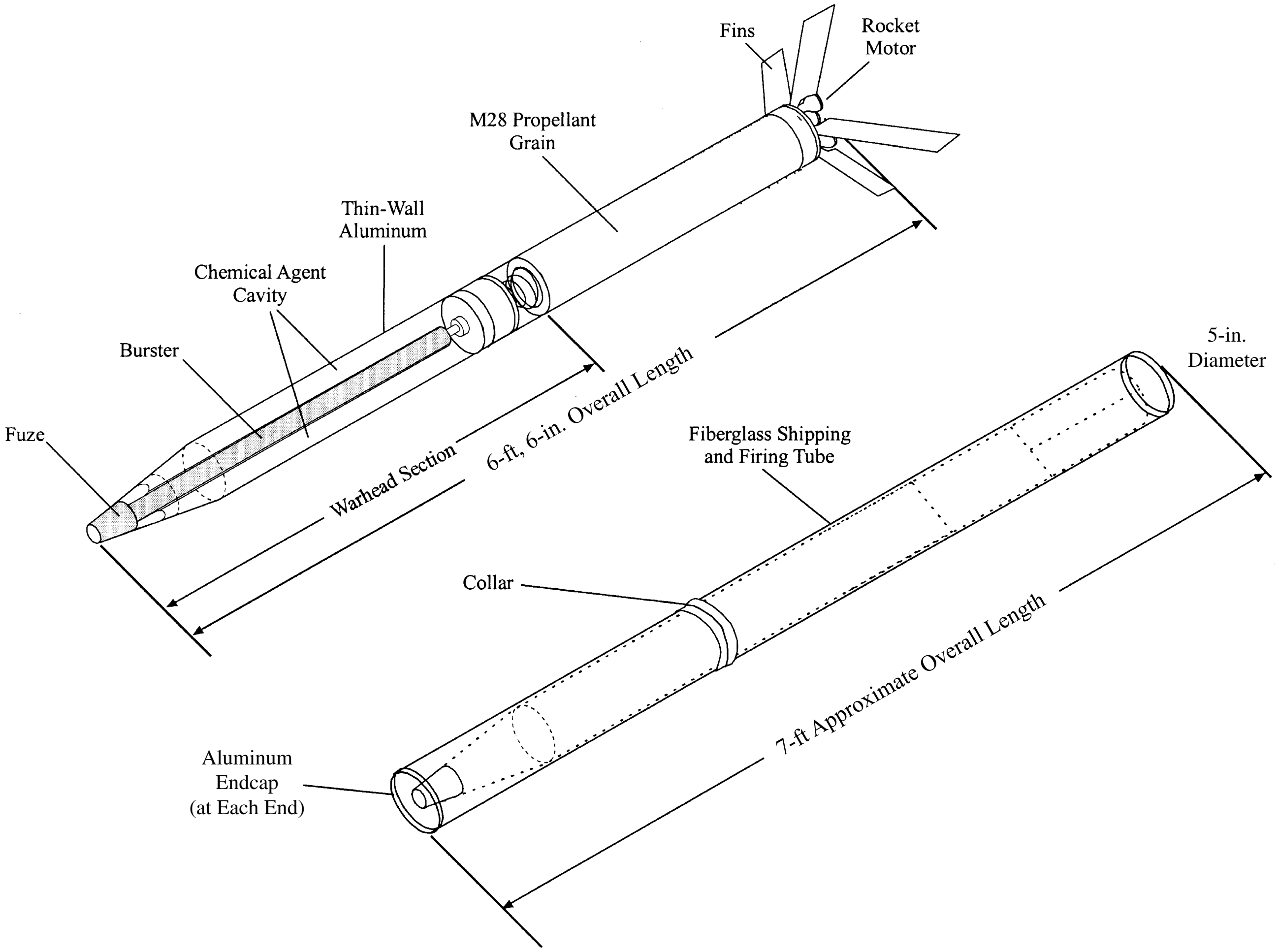

FIGURE 1-1 M55 chemical rocket. Source: U.S. Army (2002b).

erating permit that is issued by the Environmental Protection Agency (EPA) (as was the case with JACADS) or the rate authorized by a state environmental authority (as is the case with all continental U.S. sites). The rates permitted by the respective regulatory authorities for JACADS and TOCDF were in both cases equal to or somewhat less than the rate each facility was designed to handle safely. The processing of rockets in facilities using the baseline incineration system developed by the Army is described in detail in Chapters 3 and 4. Briefly, rockets are unpacked, then punched and drained of agent. The agent is transferred to a storage tank from which it is metered into a liquid incinerator (LIC), where it is burned. The drained rockets, which contain some residual agent and all the energetics, are then sheared and the parts dropped into the deactivation furnace system (DFS) rotary kiln.

No GB M55 rockets containing gelled agent were encountered during disposal processing at JACADS. However, some GB M55 rockets processed at TOCDF contained gelled agent products that would not drain as originally intended. These were sheared and dropped into the DFS with both the gelled agent and energetics.

Another issue to be dealt with during disposal processing is that some GB-filled M55 rockets have leaked during storage and have been overpacked (placed in tightly sealed containers). Processing these overpacked rockets has necessitated additional steps and increased the risk to workers. However, the total number of overpacked GB-filled M55 rockets processed at TOCDF was much smaller than the total number of gelled munitions encountered. Therefore, the delays associated with handling overpacked rockets were small compared with the longer delays associated with processing large

TABLE 1-1 Anniston Chemical Stockpile: Number of Munitions Containing Each Agent

Munition	Mustard Agent	Nerve Agent GB	Nerve Agent VX
4.2-in. mortars	258,912	0	0
105-mm projectiles	23,064	74,014	0
155-mm projectiles	17,643	9,600	139,581
8-in. projectiles	0	16,026	0
Ton containers	108	0	0
M23 mines	0	0	44,131
M56 warheads	0	24	26
M55 rockets	0	42,738	35,636

Source: U.S. Army (1995a).

numbers of gelled rockets. The same is expected to be true at Anniston.

ALTERNATIVES FOR PROCESSING GB M55 ROCKETS AT ANNISTON

Construction of the baseline incineration system facility at Anniston, Alabama, has been completed, and the facility was undergoing systemization (preoperational testing) as this report was being prepared. Systemization includes conducting trial burns in which agent surrogates are burned in the facility furnaces to test their performance. The original plan for processing rockets at the Anniston Chemical Agent Disposal Facility (ANCDF) was the same as that used at TOCDF. The Program Manager for Chemical Demilitarization (PMCD) estimated that about 20 percent of the 42,738 GB-filled M55 rockets stored at the Anniston site contain gelled agent. The VX-filled M55 rockets stored at Anniston number 35,636, but few of them, if any, are believed to be gelled. The chemical agent and munitions inventory at Anniston Army Depot consists of 661,529 items that contain 2,253 tons of agent (see Table 1-1) (U.S. Army, 1995a).

The Army believes that more gelled rockets can be safely processed per hour at ANCDF than the 1.0 or 1.6 per hour processed at TOCDF. This would decrease the total processing time and the risk of extended storage. A modified plan calls for increasing the rate to 9.2 per hour. When the Army announced that it was considering higher processing rates for ANCDF than had been demonstrated at TOCDF, local residents and governmental authorities expressed concern that disposal risks might increase. The Anniston site has more people living near it than any other site. Both the previous Alabama governor and the U.S. congressman who represented the Anniston area (and who has since become the governor) emphatically indicated that no increase in risk as a result of the processing plan modification would be tolerated (AP, 2002).[1] In this context, however, it is noteworthy that all past NRC studies and other Army-sponsored risk studies indicated that the risk to workers and the public from continued storage of the chemical agents and munitions is higher than the risk from processing (NRC, 1994a; SAIC, 1998).

The discussions in this report focus on technical considerations and related issues in going from a gelled GB M55 rocket processing rate of 1.0 or 1.6 rockets per hour to 9.2 rockets per hour, which would be 6.4 rockets per hour on the basis of an expected 70 percent availability for the DFS. Other rates are reported to reflect the variability of operational experience to date in the processing of both gelled and ungelled (drained) GB M55 rockets. Drained rockets are defined as rockets from which at least 95 percent of the agent has been removed.

STATEMENT OF TASK

Both the Army and the current governor of Alabama asked the NRC to assess the processing plan for M55 rockets stored at Anniston. Specifically, the NRC agreed to a statement of task whereby the NRC would

- Review data on the stability of stored M55 rockets, including past findings and predictions regarding the storage and disposal processing risks posed by these munitions.

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[1] Letter from Congressman Robert R. Riley, 3rd District Alabama, to Donald Siebenaler, National Research Council, July 26, 2002.

- Review operational experience from the disposal of GB and VX rockets at JACADS and GB rockets at TOCDF. Obtain data and information sufficient to compare the Army's original proposal for disposal of M55 rockets at Anniston, Alabama, with its more recent modified proposal for accelerated disposal.
- Assess the potential of the modified proposal to enable the Army to safely accelerate the schedule for disposal of M55 rockets at Anniston.
- Assess the risk and hazard analyses associated with the original and the modified proposals for M55 rocket disposal at Anniston for implications concerning potential effects on workers and the general public.

The NRC produced this report in response to the statement of task. While the report is specific to the Anniston situation, the findings and recommendations may be applicable at baseline incineration system facilities constructed at Pine Bluff, Arkansas, and Umatilla, Oregon.

ORGANIZATION OF THE REPORT

The chapters following this introductory chapter are as follows:

- Chapter 2 briefly reviews the available information on assessments conducted by the Army of the stability of M55 rockets in storage, with an emphasis on the most recent Army report on this subject (U.S. Army, 2002b).
- Chapter 3 discusses the experience with M55 rocket processing at JACADS and TOCDF.
- Chapter 4 examines the original and modified plans for processing M55 rockets at ANCDF and the risk and hazard evaluations associated with both.
- Chapter 5 contains the committee's findings and recommendations.

2

M55 Rocket Storage Condition Assessments

RECENT ASSESSMENTS OF STORAGE CONDITIONS

The M55 rocket storage conditions reviewed in this chapter refer to a number of factors related to the agent, the munitions, and the time in storage at the depot. These factors, which affect the risk of storage and/or the conditions of processing in the disposal facility, are as follows:

- Leakage of agent from a rocket, primarily because its aluminum casing becomes corroded by acid decomposition products of the agent.
- Autoignition of the rocket propellant as a result of internal heat generated by the decomposition of the propellant stabilizer, the leakage of agent into the propellant, and the overpacking of leaking rockets.
- Ignition of the stored rockets by external factors such as lightning, earthquakes, and aircraft crashes.
- Gelling of the agent in the rocket in certain more acidic GB agent lots. Gelling prevents removal of the agent in the rocket shear machine (RSM) before shearing the rocket.
- Introducing the sheared rocket pieces with the fuze, burster, propellant, and gelled agent components into the deactivation furnace system (DFS).

This report does not deal with the risk of storage associated with acts of terrorism or sabotage.

Monitoring conducted by the Army since 1973 to track the condition of the entire U.S. stockpile of chemical munitions indicated the presence of 4,781 leaking munitions as of mid-2002 (Studdert, 2002). Munitions found to be leaking require overpacking or other remedial actions. Of the 2,102 M55 rocket leakers, almost all contained GB, with leaking attributed to corrosion of the aluminum rocket casing by acids formed during agent decomposition. According to a General Accounting Office (GAO) report (GAO, 1994), 1992 Army records showed that GB M55 leakers constituted about 0.25 percent of the M55 stockpile. The GAO report also noted that the incidence of leaks in other munitions was only about 0.02 percent. More recent data have indicated that GB-filled munitions, primarily M55 rockets, continue to exhibit higher incidences of leakage than other munitions, as shown in Table 2-1.[1]

Along with leakage concerns, the Army was concerned that energetic materials (propellant, burster charges, fuzes) might deteriorate and cause autoignition, particularly in M55 rockets containing GB agent. In 1997, the Program Manager for Chemical Demilitarization (PMCD) published a report that analyzed the stability of the M28 propellant used to launch M55 rockets (U.S. Army, 1997a). M28 propellant is a double-base propellant

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[1] Although the percentage of leakers for munitions containing mustard agent H has been higher (0.46) than the percentage for munitions containing GB (0.25), there were approximately 20 times more GB munitions in the original stockpile than H munitions.

TABLE 2-1 Munition Leaks by Type of Agent

	Agent				
	GB	H	VX	HD	HT
No. of munitions in stockpile	1,546,387	77,498	497,175	931,945	270,135
No. of leakers	3,851	360	273	236	61
Percentage of leakers	0.25	0.46	0.05	0.03	0.02

Note: About half the GB and VX leakers are M55 rockets (U.S. Army, 2002a).
Source: Adapted from Studdert (2002).

containing nitroglycerin (NG) and nitrocellulose (NC); both NG and NC degrade slowly under storage conditions to generate heat and release nitrogen oxides. A stabilizer, 2-nitrodiphenylamine, is included to react with the nitrogen oxides. If the stabilizer becomes exhausted, and if the degradation rate and heat generation rate are sufficiently high, there is a possibility of autoignition. The 1997 PMCD report examined this question in detail and concluded as follows:

> The calculated results show that probability of autoignition for nonleaking rockets is extremely small, and is, in fact, below the minimum probability for inclusion in the QRAs [quantitative risk assessments]. Similarly, the results show that the safe storage life for nonleaking GB rockets extends well beyond the time required for demilitarization of the rockets. (U.S. Army, 1997a)

When the PMCD report was written, the demilitarization program for the U.S. stockpile of chemical munitions was expected to be completed in 2007. However, the risk factors calculated for the year 2012—the deadline extension allowable under the Chemical Weapons Convention, which the Army currently plans to meet—are also sufficiently small to support the conclusion of the 1997 report of the PMCD.

A report from the Edgewood Research, Development and Engineering Center concluded that if agent has leaked into the propellant, stabilizer degradation may be accelerated (U.S. Army, 1996a). Leaking rockets are placed in sealed containers ("overpacked") to prevent agent from escaping. This, however, reduces the rate of heat transfer from the rocket to the igloo and leads to more internal heating, which in turn increases autoignition probabilities. PMCD sponsored an extensive analysis of heat transfer from overpacked leaking rockets and concluded that autoignition at any site was extremely unlikely (approximate frequency of 1×10^{-5} to 3×10^{-5} per year) and that "autoignition of stored M55 rockets is not a significant contribution to public health risk" (U.S. Army, 2002b).[2] While this appears quite reasonable, the results of the study are being evaluated in detail in a National Research Council (NRC) report on stockpile degradation, due to be released later in 2003.

AGENT GELLING IN GB-FILLED M55 ROCKETS

During the processing of GB-filled M55 rockets at the Tooele Chemical Agent Disposal Facility (TOCDF), some rockets could not be drained because of agent gelling. This gelling has been correlated with certain manufactured lots of GB agent and has been attributed to the presence of diisopropylcarbodiimide (DICDI), used as a stabilizer in some lots of GB.

When GB was manufactured from 1953 to 1957 at the Rocky Mountain Arsenal, it was stored in bulk tanks and each lot was identified by an agent lot number. The production methods for these lots differed, as did their subsequent treatment. These differences are documented in Army records. In the 1960s, bulk agent was loaded into a variety of containers and munitions, each identified by a munitions lot number. Thus, each item in the stockpile is identified by both an agent lot number and a munitions lot number.

These procedures gave rise to four main subtypes of GB agent—PRO, PRO-RS, RO-RS, and RD-RS. The

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[2] The median site-specific annual autoignition probability for overpacked rockets at Anniston is 3×10^{-5} per year, which is equivalent to about one chance in 33,000 per year that an autoignition will occur. For the other three sites where overpacked M55 rockets are stored, the autoignition probability is 1×10^{-5} per year, which is equivalent to one chance in 100,000 per year. The median site-specific annual autoignition probability for nonoverpacked (undetected) leaking rockets at Anniston is approximately 1.4×10^{-6} (about one chance in 700,000 per year). The lower frequency estimate for nonoverpacked leaking rockets is due to the lower peak heat generation and slightly higher heat losses for nonoverpacked rockets compared with overpacked rockets.

acronyms used to describe these subtypes are explained as follows:

- *PRO (preroundout agent).* Agent lots of GB manufactured from 1953 to 1955 to meet a 92 percent purity specification. Tributylamine (TBA) was added as a stabilizer. Subsequent testing of these agent lots showed purities ranging from 81 to 94 percent and indicated that the TBA was mostly in the form of $(C_4H_9)_3NH^+F^-$, suggesting possible production of HF (U.S. Army, 1985, 1988). Two GB acidic degradation products, diisopropyl methylphosphonate (DIMP) and methyl phosphonofluoridic acid (MPFA), were each detected at levels from 2 to 10 percent by weight.
- *RO (roundout agent).* Agent lots of GB manufactured from 1955 to 1957 to meet a modified purity goal of 88 percent. A final distillation step was eliminated in the processing. Over the next few years, the Army continued to test the RO lots and found that they were showing significant acidity. Since some of the agent was intended for use in aluminum M55 rockets, where acidity would cause corrosion, some preventive measures were explored.
- *RD (redistilled RO).* RO lots of GB were redistilled over the next 6 years to improve purity and were redesignated as RD. In addition, TBA stabilizer was replaced by DICDI to reduce the acidity and allow the agent cavity of M55 rockets (constructed with aluminum casings) to be loaded with GB.
- *RS.* Agent lots of GB that were restabilized with DICDI were identified by adding RS to the basic agent subtype.

RO-RS lots have the highest percentage of leakers, 0.273. One GB M55 rocket lot filled with PRO-RS and stored at Anniston has a leaker percent of 0.13. Other PRO-RS lots have a leaker percent of 0.009. RD-RS lots have a mean leaker percent of 0.053. All other lots have lower percentages of leakers (SAIC, 2002a).

M55 rockets were loaded with GB from various agent lots during the 1960s. From analyses of leaker data since 1973, it appears that the more acidic GB agent lots are more prone to causing leakage, probably because they corrode the aluminum (U.S. Army, 1985, 1995b).

Gelling problems in GB-filled M55 rockets were first encountered during the GB rocket disposal campaign at TOCDF. GB gelling had previously been encountered in a few 155-mm GB-filled projectiles at the Johnston Atoll Chemical Agent Disposal System (JACADS). Gelling is identified during processing when the agent fails to drain adequately after the agent cavity of the rocket has been punched open. The degree of gelling can vary greatly—from a thickening that increases viscosity and slows the draining process to semisolid or crystalline states.

During the GB M55 rocket disposal campaign at TOCDF, almost 29,000 rockets were destroyed through the DFS at rates of up to 33 per hour, in accordance with regulatory permit allowances. Three restabilized munitions lots (5,287 rockets) were found to be gelled and were processed differently, as described in Chapter 3 (EG&G, 2002a).

The gelling originally was observed to have taken place in certain GB lots that had been restabilized with DICDI because of their inadequate purity and high acidity. It is known that DICDI can react with residual water in the GB and form 1,3-diisopropyl urea, which is insoluble in GB and forms the urea crystals that were sometimes observed during the original GB rocket and projectile filling operations that used restabilized (-RS) agent lots (U.S. Army, 2002c). Urea crystals often are observed in gelled agent lots as well. However, although gelling also seems to occur preferentially in -RS lots, the gelling mechanism now appears to be related to GB hydrolysis, which produces acidic species that react with the aluminum casing to produce aluminum phosphonate species, which, in turn, serve to link hydrolyzed GB molecules and form a viscous gel (Wagner, 2001).

Implications for Processing

For the Resource Conservation and Recovery Act (RCRA) permit for TOCDF, the Utah Department of Environmental Quality allowed a processing rate of 1.6 gelled rockets per hour through the furnace based on a simple scaling of the approved limit for agent loading in the DFS. Because there are more gelled rockets at Anniston, proceeding in this manner would significantly extend the disposal schedule. As will be discussed in Chapters 3 and 4, the DFS kiln may be able to process gelled rockets at a higher rate. An analysis that includes considerations for determining a safe rate will be presented. Of course, the DFS kiln system would have to be tested at the accelerated rate to prove its performance capabilities and to satisfy regulatory requirements.

STOCKPILE RISK CONSIDERATIONS

Quantitative risk assessments (QRAs) are developed for each stockpile site to quantify the storage and disposal risks (SAIC, 2002b). The major storage risks were found to be associated with earthquakes and lightning strikes. Risks from terrorist threats are handled separately by the Army and were not included in the public risk assessment. The frequencies for lightning-induced ignition of M55 rockets in a site stockpile range from 6×10^{-4} to 2×10^{-3} per year and for earthquake-induced ignition from 1×10^{-4} to 8×10^{-4} per year (U.S. Army, 2002b).[3] Both event ranges are slightly higher than the estimated risk of autoignition mentioned previously, but still relatively low. Nonetheless, the frequencies for these natural occurrences indicate that prompt disposal is the proper course of action. As disposal operations progress, storage risk decreases. The risk from processing is less than the storage risk, and storage risk can decline rapidly as rockets are eliminated.

Chapter 4 addresses risk implications for four processing schedule options at ANCDF. These implications are a consequence of the fact that a significant number of GB M55 rockets at Anniston contain gelled agent and of the Army's desire to process them as fast as safety allows.

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[3] The range 6×10^{-4} to 5×10^{-3} is equivalent to about one chance in 1,700 per year to one chance in 500 per year; 1×10^{-4} to 8×10^{-4} is equivalent to about one chance in 10,000 per year to one chance in 1,250 per year.

3

Processing of M55 Rockets at JACADS and TOCDF

PROCESS DESIGN FOR JACADS AND TOCDF

The baseline incineration system was first operated at the Johnston Atoll Chemical Agent Disposal System (JACADS) on Johnston Island in 1990. A series of four operational verification testing (OVTs) campaigns was conducted from 1990 to 1993 using various agents in munitions and containers to make certain the baseline incineration system was safe and effective. After the OVT program was completed, MITRE Corporation, an Army contractor, and the National Research Council (NRC) concluded that the system could operate safely and effectively (MITRE, 1991; NRC, 1994b). The baseline incineration system at JACADS was consequently authorized to complete the destruction of chemical agent and munitions stockpiles at Johnston Island. Subsequently, a second-generation facility at Tooele, Utah, began agent disposal operations in 1996, following a period of systemization (preoperational testing).

More than 7,500 GB M55 rockets on Johnston Island were processed during the first OVT campaign, OVT 1. All of the M55 rockets on Johnston Island containing VX were processed in the second campaign, OVT 2. The first disposal campaign at TOCDF was also directed at the destruction of the entire GB-filled rocket stockpile at Deseret Chemical Depot in Utah. As noted in previous chapters, some of these rockets contained gelled GB and required special processing.

This chapter describes how rockets are processed in the baseline incineration system. It also reviews the results of processing rockets and lessons learned during OVT 1 and OVT 2 at JACADS and discusses the TOCDF operations with both gelled and ungelled GB rockets.

Loading, Transport, and Unpacking

The delivery of rockets from the storage areas to the disposal facility is the first step in the disposal process. Pallets, each containing 15 rockets in individual shipping tubes secured by steel bands, are removed from storage igloos by forklifts and loaded into a transport container that is delivered by truck or tractor trailer to the disposal facility. At JACADS, each pallet was loaded into a sealed, metal vacuum box for transport (two at a time) on a flatbed truck to the facility (MITRE, 1991). At TOCDF, where the transport distance was much longer (almost 2 miles), a larger cylindrical vacuum container (8.5 ft diameter by 11 ft long), termed an on-site container (ONC), was developed and used for transport of multiple pallets towed by a tractor-trailer (U.S. Army, 1996b).

The transport containers are unloaded at the munitions demilitarization building (MDB) dock. The atmosphere of each container, maintained at subatmospheric pressure to prevent leakage to the environs, is checked for the presence of agent leaking from the rockets. Those containers in which no leaking rockets are detected are elevated to the unpack area on the second floor of the MDB. The pallets are removed from the container and the rockets are manually loaded into the rocket handling system (RHS), whose main component is the rocket shear machine (RSM). Empty containers are returned to a second dock of the MDB for return to the storage area. A limit is placed on the number of containers in the unpack area. Transport containers stored there are periodically checked to ascertain that no agent has leaked into them from the rockets or their shipping tubes.

Containers in which leaking agent is detected are directed to the explosion containment vestibule of the MDB for special handling by personnel in demilitarization protective ensemble (DPE) suits. Leaking rockets that have been overpacked are delivered to this same area for special handling and feeding into the RSM. At JACADS and TOCDF, no safety or environmental problems and no rate limitations in processing were attributable to GB M55 rocket loading, transport, or unpacking systems and operations.

Rocket Handling System

The RHSs that are installed at JACADS, TOCDF, and the other baseline facilities are virtually identical and are as shown in Figure 3-1. As noted in the figure, the first part of the RHS comprises the following:

- The rocket metering table.
- The conveyor system that carries the rocket from the metering table through gates into and out of the explosion containment vestibule, into the explosion containment room (ECR), to the RSM.
- The RSM punch-and-drain station for removing agent from the rocket, where agent is drained from the rocket into the agent quantification system—a pump, filter, measuring station, and storage vessel that allows process operators to determine how much of the original 10.7 lb of GB has been drained. Agent from the storage vessel is subsequently metered to the liquid incinerator (LIC) for disposal processing.
- The RSM shear station in which a single blade, cooled and cleaned by a flow of decontamination solution, sequentially shears the rocket into eight segments: the fuze section; the agent section and its burster into three segments; the rocket propellant into three segments; and the rocket nozzle and tail fin section.

Figure 3-2 shows the location of the cuts made in the RSM to shear the rocket into eight segments. The figure also presents information on the process in which the segments are dropped from the RSM through an angled chute into the deactivation furnace system (DFS). This process occurs in a sequence of three dumps. The volume in the chute between the two gates is water-spray cooled to minimize premature vaporiza-

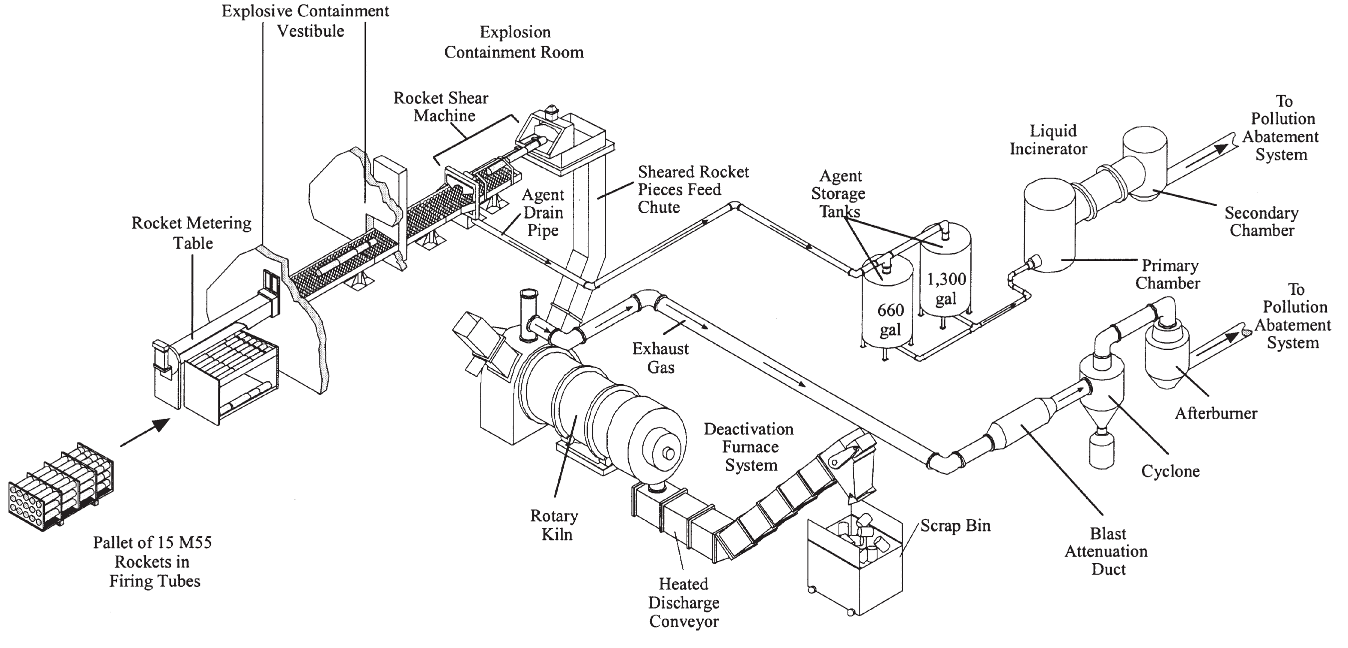
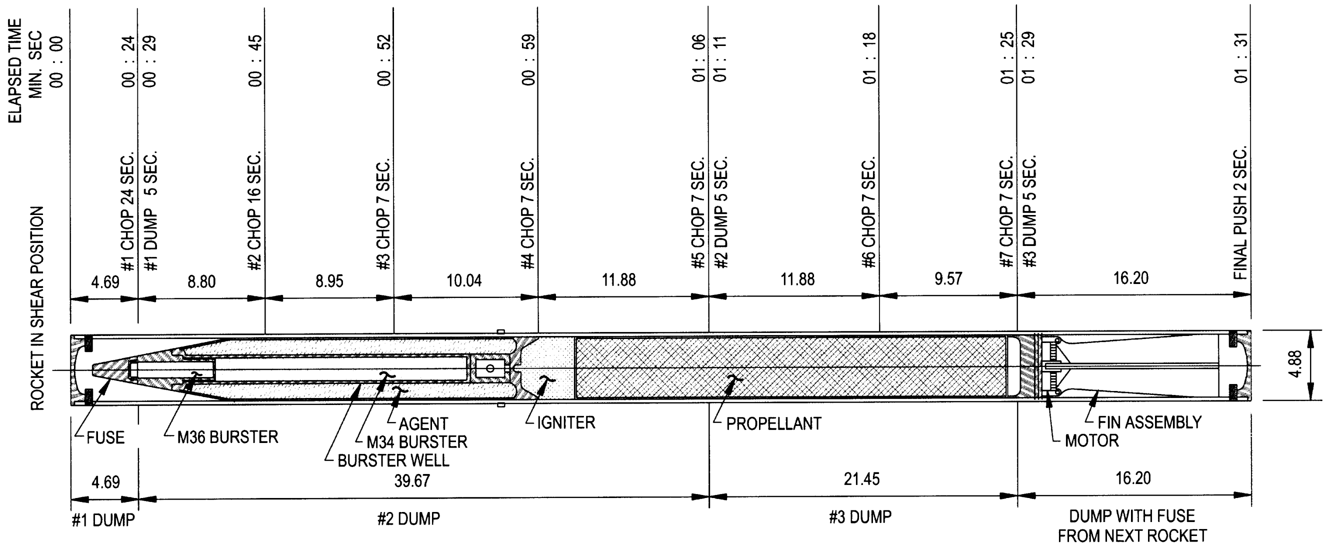


FIGURE 3-1 Rocket handling system. Source: SAIC (2002b).



CURRENT ROCKET SHEAR SEQUENCE

1) ADVANCE ROCKET TO RSM FROM RDS
2) RAISE ROCKET ENTRY BLAST GATE
3) ADVANCE NEXT ROCKET TO RDS
4) LOWER ROCKET ENTRY BLAST GATE
5) 1st CHOP (FUSE)
6) 1st DUMP (FUSE & TAILPIECE IF PRESENT)
7) PUSH ROCKET AND 2nd CHOP
8) PUSH ROCKET & 3rd CHOP
9) PUSH ROCKET & 4th CHOP
10) PUSH ROCKET & 5th CHOP
11) 2nd DUMP (4 PIECES)
12) PUSH ROCKET & 6th CHOP
13) PUSH ROCKET & 7th CHOP
14) 3rd DUMP (2 PIECES)
15) PUSH TAILPIECE
16) REPEAT STARTING AT (1)

FIGURE 3-2 Chopping sequence for 115-mm M55 rocket. Source: General Physics Corporation (2000). Note: The numbers above the doubleheaded arrows are the length of the rocket sections in inches.

tion of the agent and ignition of the energetic fuze, burster, and propellant components of the rocket.

In the first dump, the fuze is admitted into the DFS through the gates of the chute along with the tail fin section of the previously processed rocket. In the second dump, the four sheared rocket segments comprising the burster, the agent cavity, and a portion of the propellant are dropped into the DFS. In the third dump, the two remaining sheared rocket segments containing the rest of the propellant are dropped. Separating the energetics into three separate dumps or drops avoids detonating the burster and propellant by the fuze and avoids the simultaneous heat release and pressure rise that would result from the combustion of the burster with all of the propellant.

Not considered in the testing described above (and the modeling discussed in Chapter 4) is the possibility of dumping a rocket's parts into the DFS in as many as seven separate dumps. Reducing the size and Btu content of the feed packages could result in more uniform combustion within the kiln. Doing so might produce more uniform control and reduce or eliminate automatic waste feed cutoffs, but this would have to be demonstrated during the agent trial burn (ATB), when the effect of more cycling of the chute gates would also be evaluated.

Two identical, independent, parallel RSMs are installed in each of the facilities, although for simplification only one is shown in Figure 3-1. They discharge through separate chutes into a common DFS. For the most part, rocket processing at JACADS and TOCDF made use of only one of the installed RSMs at any given time (EG&G, 2002a). The operator can set the RSMs to operate between 10 and 50 rockets per hour. The original RSM design was based on an average processing rate of 32 rockets per hour, with a peak capacity of 60 per hour. Punch-and-drain time was intended to be 50 to 75 s under normal conditions.

Agent Disposal, Decontamination of Metal Parts, and Destruction of Energetics and Shipping Tubes

The original designs for the JACADS and TODCF baseline incineration system facilities were based on the assumption that 95 percent or more of the GB agent in the M55 rockets would be drained during RSM operations, stored, and subsequently processed in the LIC. The agent heel of 5 percent or less would be destroyed in the DFS along with the energetics, metal parts, and shipping tube fragments produced in the RSM operation.

The LIC has two combustion chambers. In the primary chamber, liquid agent is atomized with air and burned at 2700°F. The secondary chamber is provided with a separate burner system set for a chamber temperature of 2000°F to ensure complete combustion and agent destruction (U.S. Army, 1999a).

The principal component of the DFS is a rotating kiln about 33 ft long and 5 ft in diameter. Internal flights[1] ensure the movement of the metal parts and ash residues through the kiln. At a planned kiln rotation of ~1.85 rpm, the solids residence time is 6.5 min. The rocket and shipping tube segments produced in the RSM operation are dumped into a feed chute and slide through two blast gates into the DFS. The interlocked gates prevent the injection of rocket segments until the materials currently being processed in the DFS have moved out of the way. The gates are interlocked so that one is always closed when the other is open. This arrangement minimizes the possibility of a backflow of gases into the ECRs containing the conveyor and the RSM equipment as a result of overpressurization in the DFS. The DFS is designed to operate at between 1000 and 1500°F and processed up to 38 drained rockets per hour at JACADS (U.S. Army, 1993). Water sprays in the gas exhaust piping and the feed chute prevent excessive temperatures. The DFS kiln has an outer shroud through which the combustion air is drawn to lower the temperature of the kiln shell. Noncombustible solids pass out of the DFS kiln onto a heated discharge conveyer (HDC) that is designed to complete the decontamination of the solids to a 5X level.[2] This conveyer lifts the residues to another chute, from which they drop through gates into a residue collection bin. Drums of cooled residue decontaminated to a 5X condition are shipped off-site.

Exhaust gas from the DFS kiln goes first to a blast attenuation duct, then to a cyclone in which larger particulates are separated from the gas stream, and then to an afterburner operating at 2200°F for a residence time of at least 2 s. The afterburner and pollution abatement system ensure that agent destruction meets the required 99.9999 percent destruction and removal efficiency (DRE).

The combustion flue gases from both the LIC and DFS go to identical, parallel pollution abatement systems (PAS), in which the flue gas is first quenched with process water via a spray system that reduces the gas temperature. The gas then passes through a venturi scrubber, where 18 percent caustic solution is injected, and combines with the acid components of the gas, forming sodium salts. The salts are removed as brine in a downstream water scrubber tower and either stored for subsequent processing on-site in a brine reduction area (BRA) or shipped off-site for processing. The BRA is a set of evaporators to crystallize the brine. Although both JACADS and TOCDF had BRAs, the off-site shipping approach proved cheaper and was used at both sites.

At JACADS and TOCDF, after passing through the water scrubber tower of the PAS, the flue gas went to the stack, where it was discharged to the atmosphere. In the newer designs for other baseline incineration systems employed at Anniston, Umatilla, and Pine Bluff, the flue gas, after passing through the PAS scrubber tower, goes to a series of high-efficiency particulate (HEPA) and carbon filters, known as the PAS filter system (PFS), before going to the stack. The PFS acts as an additional safeguard by removing any remaining traces of agent and products of incomplete combustion, giving the surrounding community additional assurance that harmful emissions have been suitably controlled in a manner that protects public health.

GB M55 ROCKET DISPOSAL: ACTUAL VERSUS DESIGN RATE

JACADS Rocket Disposal Operations During OVT 1

In 1990 and 1991, the entire Johnston Island stockpile of 7,490 GB M55 rockets was processed at the newly commissioned JACADS facility over a 7-month period in its very first operation, OVT 1 (MITRE, 1991). The destruction of GB M55 rockets at JACADS took longer than originally planned (MITRE, 1991; NRC, 1994b). The RSM performed fairly well, with

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[1] The term "flight" refers to helical plates attached to the kiln shell to convey the feed materials horizontally through the rotating kiln.

[2] Solids are treated to a 5X decontamination level by holding the material at 1000°F for 15 min. This treatment results in completely decontaminated materials that can be released for general use or sold to the public in accordance with applicable federal, state, and local regulations.

about 94 percent availability. A peak rate of 32 rockets per hour was demonstrated, although the average rate of 7 per hour over the campaign was well below the design rate of 32 per hour for the baseline incineration system. The lower rate was primarily due to problems with the DFS/HDC (MITRE, 1991). The "best shift" goal is the process designer's average intended (design) throughput rate. "Full rate" goals and results are computed as about two-thirds of the design throughput rate. At JACADS, the single best shift rate achieved for GB M55 rockets was 27 rockets per hour, achieved over a 4-hour period in OVT 1 (NRC, 1994b). The full rate goal for extended periods of operation was 24 rockets per hour. Actual results over an extended period came to 15.3 drained rockets per hour, or less than half of the designer's intended rate.

The disposal rate shortfall at JACADS was attributed in general to problems associated with the start-up and shakedown of a complex, new industrial prototype facility whose associated processes had never before been operated together as a system. The goals may have been set too high (MITRE, 1991). The limited number of rockets in the GB campaign at JACADS allowed too little time to correct initial process problems and to achieve an improved, steady-state production rate. Numerous short-duration, undocumented interruptions and downtime significantly degraded the processing rate.

System component failures are to be expected during any start-up operation. Lessons learned from JACADS were used to improve the performance at baseline facilities (MITRE, 1992; NRC, 1994b).

TOCDF Rocket Disposal Operations

Although TOCDF benefited from lessons learned at JACADS and its throughput of rockets containing liquid GB was marginally better than that of JACADS, it still fell short of the design rate. The GB rocket campaign at the TOCDF processed 28,945 M55 rockets (EG&G, 2002a) and 1,057 M56 (EG&G, 2002b) warheads from August 22, 1996, through March 24, 1997, and from October 26, 1998, through August 14, 2001.

Processing at TOCDF was subject to interruptions from the gelled (thickened and crystallized) agent that was encountered in approximately one-sixth of the GB-filled rockets processed. The gelled agent clogged the agent handling system. Removal of gelled agent at the punch-and-drain station was slowed, the removal of 95 percent—called for by the design and specified in the original TOCDF (and JACADS) Resource Conservation and Recovery Act (RCRA) operating permits—was never achieved, and attempts at agent removal were continually frustrated.

Also interrupting processing were occasional DFS feed chute jams, which required removal by personnel in DPE suits, reducing the availability of the DFS. Thermal stressing of the DFS kiln led to cracks that were observed during maintenance and then repaired (Vaughn, 2002).

The HDC was another source of system downtime. Conveyor link deformation associated with high-temperature operation allowed extra slack in the system, causing rollers to disengage from the track. Molten aluminum from the rocket bodies exiting the DFS spilled and caused additional jams. Solid debris sometimes failed to dump as intended, choking the conveyor.

Processing was also slowed somewhat by the need to handle the 419 overpacked (leaking) rockets stored at TOCDF (EG&G, 2002a).

The RSMs enjoyed a very high availability rate, better than 95 percent (EG&G, 2002a). However, average production rates were restrained by other system and regulatory limitations, so that the two RSMs had mean production rates over the entire campaign of only 2.28 and 1.38 rockets per hour, respectively. The *maximum* daily production rates for RSM 1, RSM 2, and the two RSMs combined were 312 (13.0 rockets per hour), 334 (13.9 rockets per hour), and 448 (18.7 rockets per hour), respectively (EG&G, 2002a).

Gelled rockets numbering 5,287 from three specific munition lots were processed without draining. The permitted rate of only 1.0 rocket per hour delayed campaign completion, but a decision to coprocess multiple types of GB-filled munitions shortened the time that would have been needed for overall destruction of GB munitions if processing had been accomplished sequentially.

Factors Affecting Operational Experience

The very substantial difference between design and experienced disposal production rates for GB-filled M55 rockets at both JACADS and TOCDF suggests a need for careful analysis of cause and effect, including the possibility that the design production rate was set unreasonably high. The multiple causes of delay were unexpected, such as the discovery of gelled and leaking agent, equipment failures, faulty operations, and stringent regulatory limitations. The reaction of operations management personnel to each of these circumstances deserves review in light of subsequent events. This is especially true regarding regulatory limitations. Since interruption and delay at any step in a sequential process necessarily affect throughput, an analysis of the total system is required in addition to analyses of individual components.

Regulatory Limitations

DFS operation is subject to compliance with both RCRA and Toxic Substances Control Act (TSCA) regulations. TOCDF had a RCRA permit to process 33 liquid-filled rockets per hour (EG&G, 2002a). A 5 percent heel of the original 10.7 lb of GB agent was assumed to be present in each of the drained M55 rockets fed to the DFS; the corresponding flow of agent to the DFS is 17.66 lb/h (10.7 lb per rocket × 0.05 × 33 rockets per hour). While there is no indication that the agent feed rate to the DFS is limiting in terms of the 99.9999 percent DRE requirement, the emission of products of incomplete combustion, or the thermal input to the DFS, the revised RCRA permit limited the processing of gelled (undrained) GB M55 rockets to 1.6 per hour to avoid agent flows to the DFS higher than 17.66 lb/h.[3] The processing rate was further reduced to 1.0 rocket per hour when coprocessing was undertaken. Such slow processing of gelled GB M55 rockets at TOCDF significantly extended the operating schedule and slowed the reduction in storage risk.

The TSCA permit was required because a polychlorinated biphenyl (PCB) material had been used as a lubricant when some of the rockets were inserted into their firing tubes, although the quantity was very small.[4] During trial burns at JACADS, when the plant was operated at the proposed throughput rate, PCBs and controlled PCB products of combustion were found to be below permissible emission limits (NRC, 1994b). The allowable TSCA throughput for JACADS was set at 40 rockets per hour and for TOCDF at 36 per hour. The planned rate for JACADS (32) and the RCRA-established rate for TOCDF (33), which were lower, were the controlling rates (MITRE, 1993).

Impact of Leaker Processing

While the special handling required for overpacked leaking rockets is no doubt burdensome, there is no indication in the end-of-campaign reports for JACADS or TOCDF that processing leakers slowed the overall processing throughput appreciably (MITRE, 1991; EG&G, 2002a; U.S. Army, 2002d). A key reason for this view is that the number of leaking rockets was relatively small, a total of about 800 at both sites (out of more than 60,000 GB M55 rockets processed).

Impact of Gelled Agent Processing

Gelled rockets were not in evidence at JACADS so there was no impact during disposal processing operations there. At TOCDF, the story was different (EG&G, 2002a). Three munition lots (1033-55-1076, 1033-55-1077, and 1033-51-1086) totaling 5,287 M55 rockets—or 18 percent of the Deseret Chemical Depot stockpile—were identified as likely to contain gelled GB material. These munition lots were all processed through the DFS at 1.0 rocket per hour, as described earlier in this chapter. The average production rates for the three lots were 0.5, 0.5, and 0.7 per hour, respectively, for a 24-hour period (U.S. Army, 2002e). These are very much less than the "full rate" of 15.3 per hour achieved at JACADS for processing ungelled rockets. The full rate was developed by taking the total number of rockets processed during the five best production weeks and dropping the highest and lowest weeks.[5] At this rate, it would take about 367 full days of operation to process the gelled rockets [5,287/(0.6 x 24) = 367] and 67 full days of operation to process the nongelled rockets [(30,000 – 5,287)/(15.3 x 24) = 67]. Processing large numbers of gelled rockets is a much more serious impediment to production than processing large numbers of liquid-filled rockets a few of which are leakers.

COPROCESSING

In an effort to mitigate the impact of slowdowns experienced during the processing of gelled rockets, TOCDF managers conceived techniques for coprocessing munitions. Coprocessing and complementary processing have been defined for planning purposes as follows:[6]

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[3] From the notes of a meeting between a fact-finding group from the Stockpile Committee and the Army, September 25, 2002.

[4] Ibid.

[5] Information from Army answers to questions from the Stockpile Committee as a follow-up to the September 25, 2002, fact-finding meeting with the Army.

[6] Ibid.

> Co-Processing. Co-processing refers to the concurrent processing of two munition types that use different footprints of the facility and different equipment. For example, bulk items and rockets can be co-processed since they do not utilize the same handling or demilitarization processing equipment. In addition, rockets can be co-processed with non-explosively configured projectiles.
>
> Complementary Processing. Complementary processing involves the processing of two munition/bulk types that utilize a common footprint of the facility or the same equipment. For example, [the Anniston Chemical Agent Disposal Facility] ANCDF is considering complementary processing of explosively configured projectiles with gelled rockets. One ECR will be configured for projectiles, and the second one for rockets. Only one type of munition will be processed at a given time and processing of rockets and projectiles will alternate. Also, projectiles would be processed during down periods of the rocket line and vice versa.

Thus, gelled rockets could be processed through the RSM and the DFS concurrently with non-explosively-configured projectiles being processed through projectile/mortar disassembly machines, multipurpose demilitarization machines, the metal parts furnace (MPF), and the other LIC.

A safety-driven operational limitation is that the quantity of munitions in the unpack area must be controlled to limit the total energetics load in that space at any given time.[7] This was achieved by processing projectiles through the area while rocket processing was suspended for maintenance. Utah regulators granted a Class 1 RCRA permit modification to permit coprocessing, but in so doing, they limited rocket throughput to the DFS to 1.0 rocket per hour while allowing the coprocessing of 88 non-explosively-configured M360 105-mm projectiles per hour (U.S. Army, 2002f). The time required for rocket destruction was extended as a result of a cut in the disposal processing rate from 1.6 rockets per hour to 1.0 per hour, but the duration of the overall GB disposal campaign schedule was reduced as a result of coprocessing (EG&G, 2002a).

PROCESS CHANGES FROM LESSONS LEARNED

The lessons learned from the pioneering experience in processing M55 rockets at JACADS (NRC, 1994b) were adopted and built upon at TOCDF (EG&G, 2002a), which contributed uniquely because gelled rockets had not been encountered at JACADS. Lessons learned at the two facilities and applied, later on, to processing or to facility design are discussed next.

Lessons from JACADS

- *The DFS kiln wall must be able to withstand potential detonation of energetics*. It was redesigned and increased in thickness from 0.5 in. to 2 in. for TOCDF and facilities at other sites.
- *The DFS kiln flange bolts failed*. The DFS kiln is constructed in five sections that are bolted together to form a single continuous shell. During the GB M55 rocket testing, the bolts holding the kiln sections failed on three occasions. The failures of kiln bolts accounted for 120 hours (or 18 percent) of DFS downtime, the second largest contributor to total downtime. The DFS kiln bolts were replaced with bolts of improved design and different materials of construction. The replacement bolts were larger in diameter, stronger, and had a coefficient of thermal expansion that was similar to that of the kiln flanges. There were no failures of these bolts during the VX rocket campaign.
- *The HDC was jammed by slag, pieces of the rocket body, and molten aluminum*. The HDC was the largest contributor to JACADS downtime during GB rocket testing, accounting for 248 hours of the 929 hours total downtime. This was 27 percent of the downtime for JACADS and 38 percent of the downtime for the DFS. The HDC mesh conveyor was replaced by a bucket conveyor. The initial testing of the bucket conveyor indicated the drive chain assembly was inadequate for the HDC operating temperature. The chain design was then modified and the conveyor reassembled with a drive chain assembly that was identical to the one on the mesh conveyor. This modification was successful, and the only downtime associated with the HDC conveyor during the OVT 2 VX rocket testing occurred when a rocket piece jammed between the conveyor and the HDC housing. All other downtime attributed to the HDC was caused by the heater elements. The system was redesigned and additional preventive maintenance undertaken to avoid breakdown maintenance.
- *The LIC flame detector malfunctioned at high feed rates*. First, the feed rate was reduced, and then the flame scanner was properly adjusted.

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[7] From the notes of a meeting between a fact-finding group from the Stockpile Committee and the Army, September 25, 2002.

- *Glassified salt and slag accumulated in the secondary chamber of the LIC*. The refractory brick in the secondary chamber of the LIC was replaced with a spall-resistant brick. This brick was more resistant to the corrosive conditions in the secondary chamber. The original bricks were composed of alumina and silica, which reacted at high temperature with sodium from the decontamination solutions and with phosphorus from the agent to form slag, which degraded the brick. The system was redesigned to provide combustion air for each LIC to allow independent operation during slag removal. A hot tap withdrawal system was installed to drain slag from the secondary combustion chamber.
- *The DFS feed chute experienced material cracking*. The chute failed on four separate occasions, accounting for 39 hours of the downtime (6 percent of the total) for the DFS. The feed chute was replaced with one of a different design. The redesign proved to be inadequate and the chute was replaced by one of a still different design following the fourth (last) OVT test.
- *Problems with the HDC discharge gates stopped rocket processing on 11 separate occasions*. A blast enclosure was installed at the discharge end of the HDC, and the HDC discharge gates were replaced with thicker, ceramic-coated units. This reduced the number of times the gates jammed and reduced the amount of gate warping.
- *Thrust bearings on the DFS failed*. The bearings were replaced and relocated to enhance cooling and to facilitate future replacement.
- *The fuze segregator conveyor system malfunctioned*. It was removed and the rocket cutting sequence was revised to ensure separation of the fuze from other energetic components.
- *The JACADS facility was shut down by order of the Environmental Protection Agency (EPA) for 11 days during OVT 1 after the Army informed the EPA that record-keeping practices at JACADS were inadequate (NRC, 1994b)*. During the downtime, better systems were installed. For this reason, and to ensure compliance with all environmental requirements, environmental department staffing was increased.
- *The BRA as originally built at JACADS did not have a PAS associated with it because it was assumed that any emissions would contain only small amounts of nontoxic salts*. However, during OVT 1, particulate emissions exceeded the 30 mg/dscm regulatory limit, and the BRA was shut down (MITRE, 1991). While OVT 1 was proceeding, a PAS was constructed for the BRA. In October 1991 it was tested with brine from OVT 1 operations spiked with heavy metals. Although the emissions were within regulatory limits, the test was not successful. The temperature of the gas stream into the PAS for the BRA was below the dew point, which caused condensation of entrained moisture in the inlet duct. This moisture saturated the salt particulates and caused them to be deposited in the duct instead of entering the baghouse for collection (MITRE, 1993). This situation was corrected by additional heating of the gas stream. Brine produced during OVT 1 and OVT 2 was shipped off-island for disposal. During most of the OVT programs, the BRA did not operate satisfactorily. However, after modifications, the BRA did process the brines generated during OVT 3 and OVT 4, although some operating problems remained and the required BRA PAS compliance test had not yet been performed. After the OVT program had concluded, the PAS passed the test and the BRA operated satisfactorily until the closure of JACADS. At TOCDF, the BRA was installed but never used because it was cheaper to send brine off-site for processing.

Lessons from TOCDF

- *Gelled GB rockets were encountered that could not be drained of agent in the RSM as intended*. Thickened or crystallized agent plugged filters, agent collection system components, and the agent quantification system. A modification to the RCRA permit was obtained to allow rockets with a full agent fill to be processed through the DFS at a rate of 1.6 rockets per hour. Additionally, coprocessing of GB-filled munitions was undertaken. Although this reduced the allowable processing rate for gelled GB rockets to 1.0 per hour, it improved a disposal schedule that had been adversely affected by munitions containing gelled agent.
- *Overpacked leaking rockets required special handling and delayed the processing rate*. Fortunately, there were not very many of them, as noted earlier.

VX M55 ROCKET DISPOSAL AT JACADS: ACTUAL VERSUS DESIGN RATE

In addition to meeting the DRE for agent destruction and other requirements of the RCRA and TSCA permits, there were two additional process objectives during the OVT 2 with VX M55 rockets (MITRE, 1992):

- Destroy all 13,889 VX rockets stored on Johnston Island safely and expeditiously.
- Determine the effectiveness of the equipment modifications made following the GB rocket OVT 1 testing.

Three of the four TSCA DFS trial burns in OVT 2 met the 99.9999 percent DRE requirement for PCBs. The fourth just missed (99.999896 percent) (NRC, 1994b). EPA accepted this result, and nothing was done to remedy it in OVT 2. However, the trial burn results led to a rethinking of the design and operation of the DFS afterburner. In TOCDF and the other mainland baseline facilities, the residence time in the afterburner has been increased from 1 s to 2 s and the temperature has been increased from 2000°F to 2200°F.

The JACADS throughput rate and availability exceeded the goals established for the total duration of the VX M55 rocket testing during OVT 2. All of the 13,889 VX rockets were destroyed during 19 weeks of operation, which commenced on November 15, 1991, and terminated on March 31, 1992 (MITRE, 1992).

The JACADS daily average rocket throughput rate during the full rate part of OVT 2 was 20.6 rockets per hour, which was below the goal of 24.0 rockets per hour. The average throughput rate for the entire test period was 19.6 rockets per hour, which exceeded the throughput goal of 14.7 rockets per hour for the full OVT 2. JACADS was able to maintain a throughput rate of 25.3 rockets per hour for the last 10 days of OVT 2. The throughput rate was 32.0 rockets per hour during the first 10 hours of operation on March 23, 1992, which met the single shift throughput goal of 32 rockets per hour for a 10-hour shift.

The integrated system availability for JACADS was 43.4 percent for the duration of VX rocket testing in OVT 2. The integrated system availability for JACADS was 55.4 percent during the full rate portion of the test and 68.9 percent during the last 10 days (MITRE, 1992).

COMPARISON OF GB AND VX M55 ROCKET DISPOSAL CAMPAIGNS

Stack Emissions

In 1988, Congress mandated that an OVT program be undertaken at JACADS to assess the readiness of the baseline incineration system to process agent safely and effectively. The ability of the technology to meet the emission standards required under TSCA and RCRA was an important criterion in this assessment. One of the four OVT campaigns (OVT 1) destroyed GB M55 rockets, and the second (OVT 2) processed VX M55 rockets. The air emissions for all metals and organic compounds from trial burns conducted in these OVT operations met the then-current RCRA requirements with one exception (U.S. Army, 1998a): The mercury level in the MPF stack gas from GB operations was 66 $\mu g/m^3$, somewhat higher than the standard of 50 $\mu g/m^3$. Of particular note is the very low concentration of dioxin and furan in emissions from the OVT trial burns at JACADS. The measured result was 0 to 0.16 ng/m^3, which is well below the standard of 30 ng/m^3 (NRC, 1994b).

Trial burns were also conducted at TOCDF during the systemization (preoperational testing) of the facility. Lead levels in the DFS emissions from the GB M55 rocket trial burn were extremely high, 1,101 $\mu g/m^3$, well over the standard of 270 $\mu g/m^3$ (U.S. Army, 1998a). The propellant in each rocket contains 0.4 lb of lead stearate. The fuze has a lead rotor, and the detonator contains lead styphnate and lead azide. These are likely contributors to the high lead emissions, but the Army has not developed a precise rationale for why lead emissions were so much higher at TOCDF than at JACADS. As in the JACADS tests, dioxin and furan emissions in the TOCDF tests were extremely low and well below the 30 ng/m^3 standard.

Two final points are important. First, the HEPA and carbon filters that make up the PFS being incorporated into the PAS in baseline facility designs for the Anniston, Umatilla, and Pine Bluff sites should reduce emissions at these facilities below those reported for JACADS and TOCDF. Second, none of the agent trial burns conducted to date at JACADS and TOCDF have included destruction of gelled GB.

Throughput Rates

A comparison of throughput rates for the OVT tests with GB and VX rockets at JACADS reveals that the average full rate throughput increased from 15.3 rockets per hour during OVT 1 (GB rockets) to 20.6 rockets per hour during OVT 2 (VX rockets), a 42 percent increase. The maximum throughput rate demonstrated during the GB rocket testing was 27 rockets per hour for 4 hours. During VX rocket testing, the maximum throughput rate was 32 rockets per hour. This rate matched the design throughput rate and was sustained for one complete 10-hour shift (MITRE, 1992).

The integrated system availability of JACADS to process rockets increased from 33 percent during OVT 1 to 46.8 percent during OVT 2, after adjusting for the downtimes caused by the weather and the fuze segregator conveyor of the RSM (MITRE, 1992). This reflected the benefits of a more experienced workforce and learning experiences during OVT 1 that resulted in major process improvements.

Some of the improvements created another set of problems. For example, because JACADS processed rockets more rapidly during OVT 2, the DFS furnace room operated at a higher temperature. This caused the HDC heater element fuses to blow, resulting in approximately 200 h JACADS downtime. After OVT 2, the heater fuse box was relocated to a cooler location, outside the DFS furnace room.

Safety Performance

The safety performance of JACADS personnel was better in both OVT 1 and OVT 2 than the program goal. The Army elected to use the metric "cases with days away" (CWDA) per 200,000 hours worked to monitor safety performance (NRC, 1994b). The CWDA rates realized in OVT 1 and OVT 2 were 1.2 and 2.9, respectively—better than the goals of 4.1 and 3.3 that were predetermined for the operations.

A metric more often used in industry is the recordable injury rate per 200,000 hours worked (RIR). The RIR covers the CWDA cases but also includes injuries where the worker goes back to work after medical treatment. The RIR for OVT 1 was 5.8 and for OVT 2 was 5.7. These values were very high by industrial standards for ongoing operations. Army contractors subsequently improved worker safety programs and the RIRs for JACADS.

Environmental Performance

The environmental performance of JACADS continued to be a high priority during OVT 2. There were more reported instances of environmental noncompliance at JACADS during OVT 2 than during OVT 1. This was primarily due to the aggressive efforts of plant personnel to identify and correct any area that was not in strict compliance with the appropriate permit or regulation. A self-audit program was implemented to identify activities that were not performed in accordance with permit requirements. A training program was implemented to inform the JACADS workforce of the applicable permit requirements. Whenever an activity was identified as not being in compliance with the permit, the noncompliance was documented and a corrective action program was initiated. While some of the noncompliances could not be corrected during OVT 2 because long-term solutions or permit modifications were required, all instances of noncompliance were addressed. All RCRA emission limits were met. No releases of VX agent to the environment have been documented. The seawater discharge quantity and temperature were maintained within National Pollution Discharge Elimination System permit limits. All solid hazardous wastes were properly disposed of in an EPA-approved landfill (MITRE, 1992). The operation of JACADS during OVT 2 proved that the baseline system technology could be operated safely and in an environmentally sound manner. The safety program continued to function adequately.

SUMMARY OBSERVATIONS ON M55 ROCKET DISPOSAL EXPERIENCE

The following major modifications were implemented after encountering problems at JACADS:

- The DFS kiln wall thickness was increased from 0.5 in. to 2 in.
- The furnace bearings were relocated to prevent overheating.
- The HDC was redesigned to avoid downtime associated with molten aluminum problems encountered in the original design.

Notwithstanding that each site is unique with respect to the number and type of munitions stored, lot numbers represented, regulatory climate, public affairs climate, numbers and types of anomalous munitions, and to some extent, system design, a number of issues common to baseline facilities are apparent from a review of the experience in processing M55 rockets at JACADS and TOCDF:

- At JACADS and TOCDF, processing rates for the M55 rockets in the DFS were established and subsequently demonstrated in trial burns based on their handling in the RSM and on the thermal loading of drained rockets containing 5 percent or less of their original agent charge. Since gelled GB could not be drained from the rockets, the processing rate was arbitrarily reduced by a factor of 20, because a gelled rocket contained about 20 times as much agent as a drained ungelled rocket.
- Gelled GB agent will not drain as intended, necessitating identification of the anomalous rockets and the lot number of their contents and forcing the modification of some process steps. RCRA permits must acknowledge the process modifications, and programmable logic controllers must be adjusted to achieve the necessary changes in process control.
- Rocket handling and transportation to and through the unpack area are identical for gelled and liquid-filled rockets. The RSM must be reprogrammed for gelled rockets to skip the drain station and, accordingly, the agent quantification system.
- Coprocessing is a proven option for expediting the completion of a disposal campaign for GB when the need to process rockets containing gelled agent reduces throughput rates.
- The control and sensing of internal DFS kiln temperature and pressure remain challenging issues. Energetics burn quickly, producing temperature and pressure spikes. Exceedance of set temperature and pressure limits can cause thermal stress in the kiln wall and feed chute. Cracks that required repair were found in the furnace wall during inspections. Although these are not unusual in furnace operations, they are an indicator of thermal stress.
- A majority of DFS operational downtime can be attributed to three causes: HDC jams (27 percent), DFS bolt failures (18 percent), and DFS feed chute jams (6 percent). Equipment has been modified to address these causes, including a modified DFS feed chute design at ANCDF that is expected to mitigate jamming.
- Overpacked leaking rockets must be handled separately and at a somewhat slower throughput rate.
- PCBs do not present a problem in achieving appropriate DRE levels when processing M55 rockets.
- VX rockets have not shown agent gelling, and there is nothing currently known to suggest that they might.

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Processing of M55 Rockets at ANCDF

DESCRIPTION OF THE ANNISTON STOCKPILE

The Anniston Chemical Agent Disposal Facility (ANCDF) was constructed near the Anniston Chemical Activity, where stockpiled chemical agent munitions and containers are stored at the Anniston Army Depot in Anniston, Calhoun County, Alabama. The stockpile is stored in standard concrete, earth-covered igloos that are monitored to maintain the munitions in a safe and secure condition. The Anniston stockpile contains approximately 7.1 percent of the total 31,495 tons of agent in the original U.S. stockpile of unitary chemical weapons. As noted in Chapter 1, as of July 2002, approximately one-fourth of this original tonnage had been destroyed during demilitarization operations at the Johnston Atoll Chemical Agent Disposal System (JACADS) and the Tooele Chemical Agent Disposal Facility (TOCDF).

As noted in Table 1-1, the Anniston stockpile has mustard agent in mortars, projectiles, and ton containers. The nerve agent GB is contained in cartridges, projectiles, and rockets. VX nerve agent is contained in projectiles, rockets, and mines (NRC, 1994a). At Anniston, 42,738 M55 rockets are GB-filled and 35,636 are VX-filled. M55 rockets contain a total of 457,300 lb of GB and 356,360 lb of VX (U.S. Army, 1998b).

The number of gelled GB rockets at ANCDF was first estimated at about 33 percent of the inventory (Thomas, 2002). A more precise estimate based on those agent lots that are suspected to be in a gelled condition predicts a minimum of 8,706 rounds (approximately 20 percent).[1] As indicated in Chapter 2, GB-filled rockets at Anniston are more prone to leakage than munitions at other sites. A contributing factor could be the higher ambient temperatures at Anniston, which may accelerate aluminum corrosion relative to the other U.S. sites. At the time this report was prepared, 888 GB-filled M55 rockets were known to have leaked at Anniston.

Public Concerns

The Army's plans for chemical demilitarization activities at Anniston have been delayed because of troubled relations between the various stakeholders. These include personnel in charge of emergency management as part of the Chemical Stockpile Emergency Preparedness Plan, spokesmen for the Program Manager for Chemical Demilitarization (PMCD) and their contractor representatives, the Alabama Citizens Advisory Commission, and local officials ranging from the Calhoun County commissioners to the governor of Alabama and some members of the U.S. Congress. The previous governor had filed suit to postpone commencement of agent destruction operations until certain local government demands were met. That suit has since been dropped. County commissioners have repeatedly accused federal officials of failing to provide maximum protection for the surrounding populace and

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[1] Information from Army answers to questions from the Stockpile Committee as a follow-up to the September 25, 2002, fact-finding meeting with the Army.

of failing to keep promises relating to protective equipment, overpressurization of school buildings, and other protective measures. Individuals and organizations opposed to incineration technology per se have also voiced opposition to plans for stockpile disposal at the ANCDF. Steps were recently taken to overpressurize the schools, and additional protective equipment has been provided, improving the situation to some extent.

However, early in 2003, anti-incineration proponents filed suit on the grounds that proper permitting procedures were not followed. They claim that the Army should therefore be required to obtain a new Resource Conservation and Recovery Act (RCRA) permit. They also claim that neutralization technologies are now available that should be used at Anniston instead of the baseline incineration system.[2]

As the Army's stockpile disposal program has proceeded over more than a decade, the NRC has consistently urged the Army to engage community stakeholders in their activities. Some previous findings and recommendations on this topic are reviewed in Appendix A.

ORIGINAL DISPOSAL PLAN FOR THE ANNISTON STOCKPILE

The general design arrangements and proposed operations for disposal of GB M55 rockets at ANCDF are nearly identical with those employed at JACADS and TOCDF. They include loading of rockets at the storage site; transport to and unpacking at the disposal facility; processing in the rocket handling system (RHS), including draining the agent and slicing the rocket into eight sections using the rocket shear machine (RSM). Ungelled agent that is drained from rockets is processed in the liquid incinerator (LIC), and undrained gelled agent is processed in the deactivation furnace system (DFS) along with rocket energetics and metallic components. This rocket disposal system was shown in Figure 3-1.

The original disposal plan that was used as a basis for risk analyses in the Phase 2 quantitative risk assessment (QRA) for the Anniston site called for processing the GB M55 rockets first, then processing the stock of VX munitions, followed by the GB projectiles, and finally the HD/HT munitions (SAIC, 2002c). The plan assumed that rocket processing would be at the TOCDF design rate of 32 rockets per hour, implying that all the rockets could be drained to a 5 percent heel. The GB M55 rocket campaign would thus take 390 days, and the destruction of all the munitions at Anniston would take 6.9 years. The original plan did not take into account an early estimate that up to 13,000 rockets might contain gelled agent and therefore could not be drained. Even with a revised estimate of 8,706 gelled rockets, the Army has had to substantially revise the processing plans for ANCDF to allow for reduced processing rates for gelled rockets.

Rockets containing GB are the most hazardous munition because GB is the most volatile of the agents. Another factor contributing to the hazard presented by GB M55 rockets in storage is the fact that the acids formed during agent decomposition are corrosive to the aluminum rocket casing. The result is that these munitions generally have significantly higher leakage rates than other munitions in the stockpile.

M55 rockets are packed in fiberglass storage tubes, 15 to a bundle, which are stacked on pallets in storage igloos. The concern that accidental ignition of a single stored rocket might trigger a large conflagration and a release of agent was the main reason for congressional authorization for the Chemical Stockpile Disposal Program (CSDP) in 1985, as noted earlier (NRC, 1994a). Compounding this concern has been the fact that stabilizers added to the rocket propellant are gradually depleting as they react with propellant degradation products. Agent leakage into propellant may also hasten stabilizer degradation and generate internal heat. Several times over the last two decades the Army and its contractors reviewed the likelihood that these conditions could result in accidental ignition (U.S. Army, 2002a). These reviews are summarized briefly in Chapter 2 of this report and will be covered more thoroughly in a forthcoming National Research Council (NRC) report on the status of stockpile degradation under storage conditions that is being prepared by the Stockpile Committee.

MODIFIED DISPOSAL PLAN FOR THE ANNISTON STOCKPILE

Description of the Modified Plan

An initial challenge faced by the Army as it readies the ANCDF for commencement of disposal operations is to determine a safe rate for processing gelled GB M55

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[2] *Chemical Weapons Working Group et al.* v. *United States Department of Defense and United States Army*. This is a lawsuit filed in 2003 under the National Environmental Policy Act (NEPA) in the United States District Court for the District of Columbia.

rockets. A related challenge is to obtain regulatory approval to process rockets at a higher rate than the low rate allowed as a regulatory compromise and proven at TOCDF, and then to establish a schedule compatible with both regulatory approval and system capability.

Over the last decade, the NRC Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (the Stockpile Committee) has repeatedly concluded and reported that the greatest risk to the public presented by the chemical weapons stockpile is its continued storage (NRC, 1994a). The presence of gelled agent in as many as 20 percent of the 42,738 M55 GB rockets stored at Anniston, and the TOCDF precedent of reducing production rates for these rockets to limit agent loading to the DFS kiln, means it will probably be necessary to extend the disposal processing schedule beyond that originally planned. This would extend the storage period and, hence, the period of increased risk to the public, workers, and the environment. To minimize the total time for stockpile destruction at the ANCDF and to deal with the need to process gelled rockets at a reduced rate, a modified schedule of operations has been proposed.

The Army commissioned Continental Research and Engineering (CR&E)—formerly the Denver office of Maumee Research & Engineering (MR&E)—to conduct a study to determine the maximum number of gelled M55 rockets—each containing 10.7 lb of gelled agent—that could be safely processed per hour in the DFS. In May 2000, CR&E reported that the DFS could handle up to 34 gelled rockets per hour according to the modeling analysis that it had performed (CR&E, 2000). CR&E addressed a number of uncertainties and recommended that a staged ramp-up in the rate of disposal processing during the agent trial burn be followed for gelled rockets to show safe operation at a given rate before proceeding to a higher rate. This method allows demonstration of the maximum safe rate, which might be below the CR&E estimate owing to uncertainties in the analysis. A description and critique of this modified process follows later in this chapter. Based on the CR&E report, the Army decided to seek approval for an increase in the disposal production rates for gelled GB M55 rockets (CR&E, 2000). A RCRA permit modification request was submitted in June 2002 that redefined the plan for an agent trial burn (U.S. Army, 2002g). One section of the new plan proposed that 34 gelled rockets be processed per hour.

The complementary processing (described in Chapter 3 under "Coprocessing") of GB rockets and GB projectiles is another approach for schedule improvement at Anniston (U.S. Army, 1999b). According to this concept, gelled rockets would be processed for a maximum of 96 hours per week to provide 24 hours weekly for maintenance of the RHS. The rest of the time (48 hours) would be used to process GB projectiles intermittently. This complementary processing regimen could reduce the total time required for processing the rockets and the projectiles in separate campaigns. It would also reduce the number of agent changeovers required.

Coprocessing, also described in Chapter 3, will also be utilized at ANCDF, where rockets and reconfigured munitions will be coprocessed. The ANCDF processing sequence envisions the reconfiguration of many projectiles in the inventory. All energetics are removed in the reconfiguration processing step and disposed of at the depot. At the plant, while one explosion containment room (ECR) is processing rockets, the other can process the reconfigured, de-energized munitions. Agent extracted from these can be handled in the LIC, and metal parts can be processed in the metal parts furnace (MPF), all separately from the rocket process and its associated DFS. This complete separation of process equipment and flow permits simultaneous processing of gelled rockets and de-energized munitions containing the same agent (GB).

Based on the TOCDF experience, which had only one gelled GB M55 rocket in the DFS kiln at any given time, it requires 6.5 min of residence time for rocket segments to traverse the length of the DFS kiln at a kiln rotation rate of 1.85 rpm, yielding a maximum charging rate of 9.2 rockets per hour (WDC, 2002). For an assumed system availability rate of 70 percent, as was used in preparing the life-cycle cost estimates, the continuous production rate for scheduling purposes becomes 6.4 rockets per hour.[3]

A summary of the various disposal campaign plan schedules for ANCDF is given in Appendix B (SAIC, 2002c). While the estimated time required to dispose of all GB munitions is 687 days (plus 268 days for the two agent changeovers) according to the original schedule in the second column of Table A-1, it drops to 594 days without any additional changeover time if complementary processing is undertaken (fifth col-

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[3] From the notes of a meeting between a fact-finding group from the Stockpile Committee and the Army, September 25, 2002.

umn). Overall, the total number of agent changeovers would be reduced from three to two according to the modified plan, and the elapsed time would drop from 7.2 years to 6.3 years.

Rationale for Implementing the Modified Plan

The key features of the modified plan are designed to minimize the total time necessary for stockpile destruction while conforming to regulatory limitations and safety requirements. Recognizing that gelled rockets must be destroyed in the DFS and that this is going to delay the processing rate, complementary processing of GB rockets and projectiles, along with coprocessing, has been embraced as a technique for reducing the overall disposal schedule at ANCDF. Experience at JACADS and TOCDF has shown that agent changeover activity is hazardous to workers, time consuming, and expensive (SAIC, 2002c).[4]

The elimination of one changeover by implementation of the modified plan is viewed as desirable, provided the overall risk remains acceptable, both in an absolute sense and as perceived by the public. A similar decision to complete GB processing before processing VX M55 rockets was made at TOCDF because the 20-week planned changeover to VX activities could be made to coincide with the Olympic Games that would be taking place in Salt Lake City early in 2002.

EXPERIMENTAL AND MODELING RESULTS

Personnel at CR&E have broad experience in the operation of chemical demilitarization furnaces, including over 6 years with the four furnaces at JACADS. The furnaces and related equipment were field tested and proved successful, and all the furnaces (except the dunnage incinerators—DUNs—which are no longer used) have performed well, destroying about 8,000 tons of chemical munitions to date.

In 2000, CR&E examined the ability of the DFS furnace planned for ANCDF to destroy M55 rocket segments containing gelled GB. Simplified computational fluid dynamics (CFD) models were constructed of the DFS burning gelled rockets. Non-CFD modeling studies had been used by MR&E since at least 1989 in the design of the MPF of the Army's baseline incineration system. More recently, CR&E has been collaborating with Reaction Engineering International (REI) to produce and refine the CFD and reaction kinetic models for the baseline furnaces. The Army asked CR&E to estimate the number of gelled rockets that could be safely destroyed per hour. The modeling study showed that up to 34 gelled rockets per hour could be processed safely, compared with 38 ungelled rockets per hour for rockets that have been at least 95 percent drained (CR&E, 2000). CR&E recommended that "standard ramp up procedures be utilized for the shakedown period prior to the trial burn," starting at 10 rockets per hour for 2 hours (CR&E, 2000).

The first simplified model (heat transfer only) envisioned the kiln as a cylinder 30 in. in radius and 10 ft long. It contained a second, smaller cylinder 4.5 in. in diameter and 10 in. long, simulating a rocket segment. The small cylinder contained a Composition B burster charge, GB agent, and M28 propellant, all of which were assumed to be open at the ends to the ambient conditions in the kiln. The kiln gas temperature was set at 1000°F, which resulted in a steady-state, no-load wall temperature of 800°F. Under these conditions, the model predicts the propellant face temperature will reach a steady state of about 950°F in about 0.1 min. This value is above the ignition temperature, and CR&E predicted that the burster charge, agent, and propellant would "ignite within a few seconds after entering the furnace" (CR&E, 2000). The heating of fiberglass tube sections was also modeled. In this case, the combustion of the tube section should be complete after a couple of minutes (CR&E, 2000).

The feed rate was calculated from this steady-state heat transfer model, using the distance between flights (approximately 2.74 feet) to establish a separation sequence for dropping the rocket segments through the feed chute into the inlet section of the furnace. The residence time in this section was about 1 min at 1 rpm. CR&E assumed that all the heat from combustion of the rocket components would be released in this section in 1 min. The maximum 1-min average heat release the DFS could sustain was calculated from the performance experience at JACADS, where as many as 38 ungelled rockets per hour were processed. The heat of combustion from the burster charge, the propel-

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[4] During agent changeover operations, all areas exposed to agent are decontaminated by workers in DPE suits. Because automatic continuous air monitoring system (ACAMS) monitors are agent specific, monitors calibrated for the previously processed agent are replaced with monitors calibrated for the next agent to be processed. Changeover operations typically take about 4 months.

lant, and the resin in the shipping/firing tube of each drained rocket had been estimated in 1989 as 177,345 Btu (CR&E, 2000). This number does not include any Btu contribution from the agent.

The next calculation was to estimate the percentage of the GB that would burn in the inlet section (1 min at an assumed kiln rotation rate of 1 rpm). CR&E assumed that about 20 percent of the gelled GB would burn in the first minute. Combustion of the 10.7 lb of GB contained in a rocket would release 93,197 Btu, with 20 percent of it, or 18,640 Btu, released in the first minute. If this is added to the 177,345 Btu per minute heat release for the drained ungelled rocket, the total heat released per rocket in the first minute is 195,985 Btu. Then, CR&E made a simplified calculation for the rate at (177,345/195,985) × 38, or 34 rockets per hour.

Another 20 percent of the GB was estimated to burn in the second minute, and the final 60 percent was assumed to burn in the third minute.

A second model was constructed of the DFS furnace itself; it was used to test the feed rate of 34 rockets per hour with gelled agent. This could have been a very complex model; however, several simplifying assumptions were made to enable results to be calculated using a reasonable amount of computer time. One major assumption was that a steady-state condition existed with respect to heat release and the resulting kiln temperatures. The flights in the kiln were assumed to be perpendicular to the axis of flow, not spirally located as they really are. Also, hot air was assumed to be the heating medium rather than the combustion process, and no spray water was included. It was further assumed that 20 percent of the GB (2.1 lb), all of the Composition B (3.2 lb) in the burster, and all of the M28 propellant (19.1 lb) burned in the inlet section. The rest of the GB (8.6 lb) was added between the first and second kiln flights. Field data were used to set the exterior kiln wall temperature at 300°F, the interior wall temperature at 900°F, and the infiltration air at 5.2 lb/s. The rotation rate was 0.1 rad/s (about 1 rpm), which gives a residence time of 1 min in the inlet section. The output from this model showed a maximum gas temperature of about 2600°F to 3000°F 3 ft from the charge end of the kiln, decreasing to about 2200°F at the gas exhaust duct (without cooling water sprays). Since these temperatures were not deemed by CR&E to be excessive, the rate of 34 rockets per hour was recommended with the qualification that this rate "be approached gradually (standard shakedown procedure), monitoring conditions closely over a period of several hours."

CRITIQUE OF MODELING AND AREAS FOR FURTHER INVESTIGATION

While the committee respects the technical skill and accomplishment represented by the May 2000 CR&E modeling work, it believes that processing 34 rockets per hour may be unreasonably optimistic and that the actual maximum safe operating rate may be substantially lower. For one thing, if more than 20 percent of the GB is volatilized in the inlet section of the kiln by the heat released from the burster charge, the maximum heat release in the inlet section of the kiln may be higher than the 195,985 Btu/min projected by CR&E. If the heat release rate is higher, it will probably be necessary to reduce the rocket feed rate to fewer than 34 per hour to avoid excessive temperatures in the inlet section. It is possible that the peak instantaneous heat release rate could be two or more times the 195,985 Btu/min maximum heat release averaged over the first minute because the heat will not be released uniformly over this 1-min period. The CR&E assumption of a 1 rpm kiln rotation rate, rather than the planned rate of 1.85 rpm, also allows more residence time in the model system as the rocket moves through the furnace. A counterbalancing factor is the plan to utilize an air infiltration flow of up to 10 lb/s versus the 5.2 lb/s used for the model (U.S. Army, 2002h). This significantly higher air flow will help to reduce the maximum gas temperature for a given amount of combustibles in the inlet section and reduce the possibility that the DFS kiln will emit puffs of hot gases.

The DFS kiln system at TOCDF processing 1 rocket per hour had 53.5 min (60 min less 6.5 min) to cool before another rocket was charged into the kiln. If the charge rate is increased to 9.2 rockets per hour, there will be no additional time for cooling beyond the 6.5-min charge intervals. By using a low start-up rate and gradual ramping up during the agent trial burn, DFS kiln gas and metal temperatures can be monitored before deciding whether to continue increasing the rocket charging rate.

Another area of uncertainty concerns the DFS feed chute. It is probable that a significant portion of the gelled agent will melt in the feed chute, vaporize, and be thermally destroyed (thermal decomposition and/or thermal oxidation). Thermal oxidation could heat the chute to excessive temperatures if rocket sections were fed too quickly. Adequate time must be allowed for the burning rocket components to clear the chute and for the chute to cool before introducing additional rocket segments that might raise the chute temperature excessively.

Another concern directly related to the peak instantaneous heat release rate is transient pressure puffs occurring when large quantities of highly volatile materials burn within a short time. If the pressure in the kiln shroud (through which the combustion air from the DFS kiln is aspirated) becomes higher than the ambient external pressure, there could be a short-term release (puff) of gases into the DFS furnace room and/or into the ECR.

Still another concern is the possibility of cracks in the charge chute and DFS kiln shell, as happened at TOCDF, where they were probably the result of thermal stresses caused by intermittent (unsteady-state) charging of rocket pieces, especially when gelled GB rockets were being charged only once per hour. The committee believes these thermal stresses at ANCDF might be less at a charging rate of 9.2 rockets or more per hour and might produce less cracking than occurred at TOCDF because the chute and kiln metal temperatures would remain more uniform (i.e., the heat released over a given 1-h period would be more uniform at 9.2 rockets per hour or more than at 1.0 or 1.6 rockets per hour.

DETERMINING THE MAXIMUM SAFE OPERATING RATE

The experience gained at TOCDF from having one gelled rocket in the DFS at a time is clear. As discussed elsewhere, this experience would support an assumption of a maximum processing rate of 9.2 rockets per hour. At an availability of 70 percent, this yields a full rate of 6.4 gelled GB rockets per hour. However, because of the concerns cited above, the committee does not believe the processing goal of 9.2 gelled rockets per hour or any rate above the proven 1.0 or 1.6 rockets per hour has been confirmed by the modeling work so far. The actual maximum safe operating rate may be more or less than the 9.2 per hour goal. The only way to establish a maximum safe rate is to test for it during the agent trial burn. Therefore, the Army plans to start at a rate of two gelled rockets per hour and to demonstrate over a period of at least 2 weeks that observed pressure and temperature fluctuations are within design limits at this rate. Once this is achieved, a ramp-up to four rockets per hour seems prudent. Again, safe performance must be demonstrated for 2 weeks before a further ramp-up to six rockets per hour is attempted. This process should be continued until the maximum safe operating rate has been determined (DePew, 2000; Thomas, 2002).

With regard to ramp-up during the agent trial burn to establish an optimum safe performance rate in the throughput tests, all relevant existing process measurements acquired from the Process Data and Recording System of the baseline incineration system during previous operations will need to be evaluated. In addition to the use of five infrared pyrometers along the length of the kiln to measure the kiln shell temperature profile, the following continuous, real-time measurements should be made at least every 2 s and recorded on high-speed continuous recorders for the time periods of interest to determine the maximum feed rate:

- Differential pressure between the lower end of the feed chute and the surrounding room using at least two differential pressure transmitters with low draft range.
- Gas temperatures in the lower feed chute and the gas exhaust duct using at least three fast-response thermocouples.
- Metal temperatures with at least two thermocouples located close to the section of the chute nearest the DFS kiln.

Even with the added measurement and monitoring capabilities mentioned above, some further modeling may be desirable in order for operators to understand and interpret field measurements.[5] This may bolster the understanding of combustion efficiency issues. Graphic visuals from the models might prove useful in this regard.

SCHEDULE IMPLICATIONS

The processing of GB M55 rockets, agent changeover, and the processing of VX M55 rockets are typi-

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[5] The committee has learned that a more comprehensive model of DFS operations on GB M55 rockets has recently been constructed by Reaction Engineering International and CR&E. This computational fluid dynamics (CFD) model apparently reproduces quite accurately the actual operating results of processing GB M55 rockets at JACADS and TOCDF—for example, average DFS exit gas temperatures and exit gas oxygen contents. The work is described in "Computational Modeling of a Chemical Demilitarization Deactivation Furnace System" (Denison et al., 2003). The paper was presented in May 2003 at the 22nd Annual Conference on Incineration and Thermal Treatment Technologies in Orlando, Fla.

cally the first tasks scheduled at chemical demilitarization facilities in order to minimize overall risk to workers and the public. However, in planning ANCDF operations, such a schedule would prolong the overall time required because of the need for an additional agent changeover to complete the disposal of GB projectiles after completing the disposal of all VX munitions. The additional changeover would probably contribute additional worker risk.

Complementary processing would reduce the time and cost of the overall ANCDF operations and contribute to eliminating the risk from the stored stockpile at Anniston sooner. However, the risk management analysis of August 2002 indicates that if complementary processing is undertaken, the GB M55 rocket campaign would be extended and the VX M55 rocket campaign delayed by some 120 days by interspersing GB projectile processing (SAIC, 2002c).

Additional concerns associated with munitions delivery during complementary processing periods at the Anniston site are these:

- Deliveries of two types of munitions via on-site containers (ONCs) on trucks and trailers from storage igloos to the unpack area of the container handling building would require careful planning and scheduling. There would need to be adequate quantities of munitions on hand for processing in the two individual lines, and deliveries of one type of munition would need to be kept from interfering with delivery and storage of the other type of munition in the unpack area of the container handling building. The risks associated with munitions delivery and storage at ANCDF have in general been estimated to be minimal (SAIC, 2002b).
- There could be long-term effects of agent and decontamination solution splashes in and around the RSM and the chute. However, there was no indication in the end-of-campaign reports on rocket processing at TOCDF that the processing of gelled M55 GB rockets decreased the availability of the RHS, including the RSM.

The TOCDF experience with gelled rockets shows that a destruction and removal efficiency (DRE) of 99.9999 percent is unfailingly achieved with a kiln residence time of 6.5 min. Based on this residence time, the committee believes that a DFS processing rate of 9.2 rockets per hour (with a 70 percent availability rate) will prove feasible and safe. Such a rate would allow only one rocket in the kiln at any given time.

In a seminal 1994 report, *Recommendations for the Disposal of Chemical Agent and Munitions*, the Stockpile Committee considered the options for configuring a chemical agent and munitions disposal facility based on incineration technology (NRC, 1994a). The report confirmed the Army's earlier decision that four separate furnace systems should be installed to handle agent, energetics, metal parts, and dunnage. The reason for this was that the separation of these streams was considered an important safety feature of the baseline incineration system. The report states that the separation into streams ". . . provides the designer the freedom to tailor the design of each disposal system to the properties of the separate (and quite different) materials to ensure safe, controllable operations" (NRC, 1994a).

The separation of streams idea was followed in the original designs for JACADS and TOCDF. However, as operating experience was gained and specific problems and opportunities arose, changes were made in the original design concept. Four specific examples of process evolution follow:

- The dunnage incinerators at JACADS and TOCDF were not operated because it was determined that the dunnage (pallets, containers, DPE suits, etc.) could be stored safely and then processed through the MPF periodically or shipped off-site. Accordingly, the dunnage incinerator was omitted from the ANCDF design.
- The Army also determined that the brine reduction area (BRA) was not needed since the brine could be processed safely off-site and at lower cost. Although the BRA was included in the ANCDF design, its use is not currently intended (personal communication between Col. Christopher Lesniak, PMCD, and the M55 Committee on February 4, 2003).
- The third example of process evolution, PAS filter systems (PFS), was not in the JACADS or TOCDF designs but was installed at ANCDF and the other new baseline facilities. The PFS uses high-efficiency particulate air filters and beds of activated carbon to treat flue gas at these facilities. Its purpose is to further reduce the already low traces of various products of incomplete combustion and metals and virtually eliminate the

possibility of an accidental release of chemical agent through the stack. This modification should serve also to enhance public confidence in the safety of the disposal operation (NRC, 1999).

- The fourth example is the development of a modified baseline process concept for processing mustard agent munitions at the Pueblo, Colorado, site (NRC, 2001). This process utilized a single MPF to process agent and metal parts simultaneously. The energetics would be handled in a DFS or sent off-site.[6]

These four examples show that the baseline incineration system is continually being modified by evolutionary development and operational improvements to enhance safety or to increase efficiency while maintaining a high standard of safety. Improvements may stem from lessons learned during the course of operation or the need to meet newly identified, specific processing requirements.

The proposal put forth by the Army for processing gelled GB M55 rockets at ANCDF is the most recent example of attempting to meet new processing needs. As pointed out in Chapter 3, crystallized or gelled agent was unexpectedly encountered in some of the GB rockets processed at TOCDF. Special permit modifications had to be obtained to allow their processing, but these modified conditions slowed the disposal. At Anniston, which has roughly twice as many gelled rockets as Tooele, the delay could be significant and would increase storage risk. The Army's experience at TOCDF in processing gelled GB rockets, coupled with sufficient modeling and agent trial burn testing for safely increasing the throughput rates during DFS operations at ANCDF, could lead to an improved processing sequence that saves time and reduces storage risk.

RISK IMPLICATIONS OF ACCELERATED PROCESSING

The Chemical Stockpile Disposal Program (CSDP) was established to destroy the U.S. stockpile of unitary chemical weapons while ensuring maximum protection of the general public, personnel involved in the destruction effort, and the environment. To attain this goal, PMCD established effective risk management systems, outlined in its *Guide to Risk Management Policy and Activities* (U.S. Army, 1997b). The guide defines the process and a series of assessments to be used to evaluate CSDP project risk and discusses how the assessment results are used in decision making to ensure that any changes to a project will not be made unless the changes continue to provide maximum protection to the public, workers, and the environment. In accordance with this guidance, the storage risk, the worker risk, and the general public risk from agent exposure were extensively investigated in developing the Phase 1 and Phase 2 QRAs[7] for the Anniston site. However, because the original schedule plan for disposal (see the second column in Table B-1) was used for the analyses, the QRAs did not provide for schedule extensions associated with having to process gelled GB M55 rockets at a reduced rate in the DFS. Consequently, the QRAs also assumed that the GB M55 rocket campaign would be followed by the VX campaign (with all M55 rockets being destroyed first) and that the remainder of the GB munitions would be destroyed next, followed by the HD/HT stockpile.

Public Risk

The public risks calculated in all the QRAs performed to date show that the risk associated with continued storage is larger than the risk associated with processing (SAIC, 2002).[8] These values were estimated using a comprehensive QRA methodology, which was reviewed earlier by the NRC in a risk report (NRC, 1997). Thus, the public risk is essentially controlled by the duration of potential exposures from stored stockpile components. Table 4-1 shows the revised QRA public risk estimates for Anniston for the four schedules shown in Table B-1 in Appendix B. The risk compared in Table 4-1 is the Public Acute Fatality Risk, which is the estimated expected number of fatalities

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[6] A separate NRC committee examined alternative technology options for the Pueblo disposal facility while the Stockpile Committee prepared its report on a modified baseline process. The modified baseline process and an alternative neutralization-based process were separately determined to be technologically feasible. The neutralization process was selected after all factors, including public reaction and preferences, were considered.

[7] A Phase 1 QRA evaluates public risks from a proposed facility before it is constructed. A Phase 2 QRA is a detailed evaluation of the risks and consequences of accidental releases of agent to workers and the community based on the site-specific design and operations.

[8] In general, risk estimates of fatalities in QRAs are arrived at by considering the probability of an accident occurring in combination with the likely consequences of such an accident.

TABLE 4-1 Comparison of Storage Risk for the Anniston Public Under Four Different Rates of Rocket Disposal

	Total Public Risk of Storage from Start to Completion of Disposal Processing
Schedule Option	Public Acute Fatality Risk (Mean)[a]
Original schedule—32 ungelled rockets per hour	5.1×10^{-2}
Original schedule—9.2 gelled rockets per hour	5.8×10^{-2}
Modified schedule—9.2 gelled rockets per hour	6.5×10^{-2}
Modified schedule—1.6 gelled rockets per hour	9.5×10^{-2}

[a] These numbers range from 0.051 to 0.095 fatalities.
Source: Adapted from SAIC (2002c).

over the planned duration of the disposal process for each of the four options.

The original schedule risk is not applicable unless gelled rockets can be processed through the DFS at the same rate as drained ungelled rockets. This seems unlikely, and even if it were possible, the delays in demonstrating its safety would probably more than offset the time that would be saved by processing at this rate. Table 4-1 shows that for the projected rate of processing gelled GB M55 rockets, 9.2 rockets per hour, moving from the original schedule to the modified schedule entails some increase in public risk. This increase is associated with delaying the destruction of the VX M55 rockets by about 120 days while the other GB munitions are destroyed. Storage of VX M55 rockets poses a higher risk than storage of the other GB munitions. However, it is useful to note that the differences in these risk estimates are less than the uncertainty ranges associated with the absolute numeric estimates of risk, and that other sources of 4-month delays can cause equivalent increases in public risk.

Worker Risk

Industrial accidents include all manner of non-agent-related injuries, such as cuts and falls. The work demands at a chemical agent disposal facility may be more complex than at a typical industrial facility. The committee believes that continuing improvement in training and attention to rules are essential to the safety of CMA operations. The need for this continuing improvement was a consistent theme of earlier NRC reports, as exemplified by Recommendation 13 from *Evaluation of Chemical Events at Army Chemical Agent Disposal Facilities* (NRC, 2002b):

> **Recommendation 13.** A generous allotment of time should be given to training and retraining chemical demilitarization plant operating personnel to ensure their total familiarity with the system and its engineering limitations. All plant personnel should receive some education on the total plant operation, not just the area of their own special responsibility. The extent of this overall training will be a matter of judgment for plant management, but the training needs to focus on how an individual's activities affect the integrated plant and its operational risk. Each facility should develop training programs using the newly-designed in-plant simulators to simulate challenges that require knowledge based thinking. The training programs should include a process for judging the effectiveness of the training. Including "design" experts in the start-up crew for new plants could be helpful in identifying latent failures in process and facility design.

The likely number of disposal worker fatalities from agent contact during processing was estimated to be 0.5 over the anticipated 7-year disposal period. This is the calculated result of a very detailed fault tree analysis covering a wide variety of conceivable accidents and mishaps. It is higher than average industrial experience, which would predict about 0.1 fatality for the same work period (SAIC, 2002b). It should be recognized that these probabilities are the best estimates from risk experts working in the field. The fact that there has not been an agent-related fatality in the 20 years of combined experience at JACADS and TOCDF suggests that these computed values may be high. The one worker fatality that has occurred happened during a maintenance operation, while JACADS was shut down. It was not related to the presence of agent.

The QRAs do include some worker risks associated with agent changeover periods, but these risks have not been developed in detail because of the perception that risks are reduced when agent processing is stopped between disposal campaigns. The committee notes that there have been several agent events while facilities are in shutdown condition (NRC, 2002b). A recent incident involved a release of VX outside engineering controls during processing of waste materials at JACADS; another recent incident involved the release of GB during agent changeover operations at TOCDF. The latter occurred inside engineering controls but did involve exposure of two workers to a nonlethal concentration of GB. The Army has observed a higher frequency of unplanned events when nonroutine operations, including maintenance and changeovers, are being performed.[9] Therefore, the worker risks associated with changeovers may not be fully considered in current QRA estimates.

The net impacts on worker risk of the modified plan scenarios for ANCDF are difficult to assess. For example:

- Worker risks are increased due to complementary processing activities, but the total time of worker exposure to risk is decreased.
- Risks to workers are decreased by the elimination of one changeover period if all GB munitions are processed together.

Although detailed worker risk analyses for the scenarios in Appendix B that consider processing of gelled GB rockets have not been done, it is likely that worker risk is somewhat reduced for the modified schedule with processing at 9.2 (sustained rate of 6.4) gelled rockets per hour.

Health and Environmental Risks

Chemical agent disposal operations can pose other, more general risks to the public. These may be health risks posed by exposure to hazardous materials other than chemical agents—for example, from stack emissions of metals or organic materials. Estimates of the extent of this risk are contained in a health risk assessment (HRA). The development of the HRA for Anniston required data from yet-to-be-performed agent trial burns; consequently, an HRA could not be made available to the committee when this report was being prepared. Emissions over the course of destroying the stockpile at Anniston will produce small receptor exposures to nonagent emissions within regulatory guidelines, and it does not appear that shifts in schedule of the type envisioned in the modified schedule options given in Table B-1 will have much, if any, effect on the Anniston HRA.

Although data on the security risk from extended stockpile storage were not provided to the committee, it is intuitively obvious that the longer weapons of mass destruction are maintained intact, the greater the risk of misappropriation and misapplication by an unauthorized person or persons.

Overall Risk to the Public, Workers, and the Environment

The minimization of risk to the public, workers, and the environment is a guiding precept of the CSDP. With regard to the options for processing rockets containing gelled agent at Anniston, it appears that maintaining the original schedule probably entails increased *worker* risk because of the additional agent changeover needed to expedite processing of VX M55 rockets before completing the processing of other GB munitions. On the other hand, the original schedule reduces *public* risk by a small amount by eliminating the VX M55 rockets about 4 months earlier. However, neither the original nor the modified schedules will minimize *both* public and worker risk. Thus, the Army will have to make a decision that is based on judgment and proactive consultation with regulators and other concerned parties.

SURROGATE TRIAL BURN IN THE DFS

From May 29 through June 4, 2002, ANCDF conducted a surrogate trial burn in the DFS using an agent surrogate. The surrogate was a mixture of 67 weight percent liquid monochlorobenzene (MCB) and 33 weight percent solid hexachloroethane (HCE) (U.S. Army, 2002i). MCB was chosen because it has thermally stable bonds and is harder to destroy than agent. HCE was selected because it simulates a solid gel and has a high chlorine content. This mixture challenges the combustion efficiency of the DFS and the ability of the PAS to remove the acid hydrogen chloride (HCl) gases. Three sets of test conditions were employed:

- a low-temperature test (LTT) without the PFS
- a high-temperature test (HTT) without the PFS
- an HTT in which the PFS was operating (HTT-PFS)

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[9] Personal communication between Conrad Whyne, PMCD, and the Committee on Review of Army Planning for the Disposal of M55 Rockets at the Anniston Chemical Weapons Disposal Facility, March 26, 2003.

The LTT was designed to demonstrate the permit limits for maximum hourly rolling average feed rates and minimum combustion temperatures. The DFS inlet was kept at more than 950°F (i.e., a nominal operating temperature of 1100°F). The afterburner operated in a temperature range between 1700°F and 2200°F (i.e., a nominal operating temperature of 1850°F). The heated discharge conveyor ran at 1000°F or hotter. A plastic bottle containing approximately 7.6 lb of the surrogate was put into a wet burlap bag and fed to the DFS through the feed chute every 106 s. The total surrogate feed rate was 257.1 lb/h. This was intended to approximate the heat release from feeding the GB in 34 gelled rockets per hour, or 363.8 lb/h. However, each gelled rocket also contains 3.2 lb Composition B burster charge, 19.1 lb M28 propellant, and 7.2 lb epoxy resin in the fiberglass shell, a total of 29.8 lb of other combustible material. This was not compensated for in the LTT but was to some extent in the HTT and HTT-PFS tests.

The HTT and HTT-PFS test conditions were designed to test the maximum hourly rolling average feed rates for metals and the maximum hourly average kiln temperatures (U.S. Army, 2002i). A high chlorine injection rate was employed because the volatilization rates of metals increase in a high chlorine atmosphere. The DFS temperature was held at the same condition as in the LTT (a nominal operating temperature of 1100°F), but the afterburner ran much hotter, at a nominal operating set point of 2150°F. Plastic bottles in this case contained 19.4 lb of a mixture of metal oxides (11 weight percent), ethylene glycol (56 weight percent), MCB (17 weight percent), and HCE (16 weight percent). The ethylene glycol was added to boost the thermal loading of the surrogate feed to that of a gelled GB M55 rocket, including energetics. A bottle was charged every 112 seconds for a total feed rate of 621.6 lb/h.

Three runs were made under each test condition, so there were nine runs altogether. Selected data from these nine runs are summarized in Table 4-2 (U.S. Army, 2002j). The highest measured emission rates or concentrations for each test condition are listed. Values that are above allowable standards are in boldface type.

The regulatory 99.9999 percent DRE targets for agent surrogate destructions were met. There were 21 metals injected in the HTT trials, and all except cadmium, lead, and mercury tested within permit limits in the exhaust gas. However, the PFS was able to reduce these three emissions to well below the permit levels. Vinyl chloride was not detected, but the detection limit of the analytical equipment was so high it was not possible to judge if the standard was met or not. Only 1 of the 17 substances of potential concern (SOPCs), tetrachlorodibenzofuran, was above the limit; the rest were not, and the total ITEQ[10] levels for polychlorinated dibenzo-*p*-dioxins and dibenzofurans were very much lower than allowed. Carbon monoxide levels were also very low, which indicates that products of incomplete combustion were minimal. Chlorine, HCl, and particulate emissions were also very low.

On September 1, 2002, the Alabama Department of Environmental Management (ADEM) approved the surrogate trial burn report and asked ANCDF to make it available for public review (ADEM, 2002). A surrogate trial burn was also undertaken at the LIC furnace from March 16 to March 23, 2002. The results are available but are not germane to the processing of gelled rockets and so are not covered in this report (U.S. Army, 2002k). On December 20, 2002, ADEM also approved that report.

The DFS surrogate trial burn enhances the prospects that more than 1.6 gelled GB M55 rockets per hour can safely be processed through the DFS. However, the conditions in the furnace when rocket segments are charged may be much different from conditions when bags of surrogate, each representing either the agent content alone or the agent and energetics content of a rocket, are charged. Proof for the ability of the DFS to process more than 1.6 gelled GB M55 rockets per hour awaits an agent trial burn. In June 2000, the Army submitted a RCRA revision to test processing of 34 gelled rockets per hour. However, in 2002, the Army revisited its plans for processing 34 rockets per hour. A new procedure calls for processing one gelled GB rocket in the DFS kiln at a time, with 6.5 min residence time, for a total theoretical maximum processing rate of 9.2 gelled GB rockets per hour (U.S. Army, 2002m). Taking into account a 70 percent DFS availability yields a maximum full rate of 6.4 gelled GB rockets per hour.

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[10] International toxic equivalency quotient (ITEQ) dioxin is the amount of 2,3,7,8-TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) with toxicity equivalent to the complex mixture of 210 dioxin and furan isomers with between 4 and 8 chlorine atoms found in flue gases. This equivalency is based on the International Toxic Equivalence Factor scheme adopted by EPA and most countries to simplify the reporting of dioxin emissions.

TABLE 4-2 Results of ANCDF Surrogate Trial Burn Runs for the DFS[a]

Parameter	Condition 1 LTT	Condition 2 HTT	Condition 3 HTT-PFS	RCRA or CAA[b] Permit Limit
DRE for MCB, %	>99.99994	NA[c]	NA	99.9999
DRE for HCE, %	>99.999997	NA	NA	99.9999
HCl, g/s	<6.40E-04	<6.81E-04	<6.48E-04	1.66E-02
Cl_2, g/s	<2.71E-03	<2.00E-03	<2.14E-03	4.03E-03
HCl / Cl_2 ppm at 7% O_2	<0.60	<0.48	<0.50	21
HF, g/s	<6.52E-04	<6.93E-04	<6.60E-04	1.718E-02
Particulates, lb/h	≤0.049	≤0.086	£0.053	1.18
Particulates, g/dscf at 7% O_2	≤0.00084	≤0.00126	£0.00076	0.015
NO_x, lb/h	≤3.0	≤4.5	≤4.75	112
SO_2, lb/h	≤6.25	≤6.5	≤5.0	14.5
CO, ppmv	≤0.02	≤0.51	≤0.10	100
Cadmium, g/s	NA	**<4.00E-04**	<2.60E-06	1.36E-05
Lead, g/s	NA	**<1.98E-03**	<1.43E-05	3.49E-04
Mercury, g/s	NA	**<6.82E-05**	<2.90E-06	5.42E-06
Vinyl chloride, g/s	**<1.00E-05 [ND]**[d]	NA	NA	1.67E-06
Benzene, g/s	<1.56E-05	NA	NA	1.14E-04
Total PCDD/PCDF, ng TEQ/dscm at 7% O_2	<0.023	<0.041	<0.028	0.20

[a] The values reported for Conditions 1, 2, and 3 are the highest values measured during three test runs. Values above allowable standards are in boldface type.
[b] Clean Air Act.
[c] Not applicable.
[d] Not detected.
SOURCE: Adapted from U.S. Army (2002j).

APPLICABILITY OF THE PROPOSED PROCESS FOR ANNISTON TO OTHER SITES

The applicability of the proposed modified Anniston process to other sites depends on the presence of gelled GB agent in M55 rockets at those sites, as well as on the regulatory and public relations climate. The Army has estimated that gelled rockets are present at Umatilla but amount to only 3 percent of the total (2,791 of 91,375 GB M55 rockets in storage).[11] Processing this small number at the TOCDF rate would extend the rocket campaign by $2{,}791/(1.6 \times 24) = 73$ days. If the Anniston modified system could be employed, the time required to destroy gelled rockets would be extended by $2{,}791/(6.4 \times 24) = 18$ days. The campaign extension could therefore be reduced by 55 days if the Anniston modified process can be employed at Umatilla. This modest improvement and reduction of storage risk might not warrant the problems encountered in seeking regulatory approval and public understanding of the schedule change.

Because the stockpile at Pine Bluff is not believed to contain any of the agent lots known to exhibit gelling,[12] there would be no perceivable benefit to employing the modified disposal plan for ANCDF at Pine Bluff. The stockpile at Blue Grass is to be destroyed by neutralization-based technology. Since a DFS is not a component of this technology, the Anniston modified disposal plan is not applicable to the Blue Grass site.

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[11] Information from Army answers to questions from the Stockpile Committee as a follow-up to the September 25, 2002, fact-finding meeting with the Army.

[12] Ibid.

5

Findings and Recommendations

The findings and recommendations below are numbered according to the chapter of the report from which they derive and are grouped according to the element to which they pertain in the statement of task (SOT) for this report.

> **SOT Element 1.** Review data on the stability of stored M55 rockets, including past findings and predictions regarding the storage and disposal risks posed by these munitions.

Finding 2-1. The committee qualitatively evaluated past findings and predictions developed by the Army of the risk of autoignition of leaking and nonleaking GB M55 rockets, and it concurs with the conclusion from these studies that the absolute risk from M55 rockets during continuing storage is reasonably low. However, in a relative sense, these rockets have the highest storage risk of any group of chemical munitions and should be disposed of as soon as and as rapidly as possible. A more detailed review of stockpile degradation will be forthcoming in a National Research Council report currently in preparation.

Recommendation 2-1. The Army should continue to give safe and expeditious disposal of GB M55 rockets a high priority in munition destruction campaigns.

Finding 2-2. Some of the GB M55 rockets processed at the Tooele Chemical Agent Disposal Facility (TOCDF) contained gelled agent. These rockets came from three particular agent lots that contained restabilized agent. No gelled rockets were found among the munitions processed at the Johnston Atoll Chemical Agent Disposal System (JACADS). The gelled rockets at TOCDF were processed at the conservatively permitted rate of 1.6 per hour (compared with as many as 33 per hour for ungelled rockets). Processing at this low rate would extend the disposal schedule by about a year at the ANCDF.

Recommendation 2-2. The Army should continue to examine and establish options for accelerated processing of gelled GB M55 rockets that satisfy safety and regulatory requirements.

> **SOT Element 2.** Review operational experience from the disposal of GB and VX rockets at JACADS and GB rockets at the TOCDF. Obtain data and information sufficient to compare the Army's original proposal for disposal of M55 rockets at Anniston, Alabama, with its more recent modified proposal for accelerated disposal.

Finding 3-1. A large number of problems were solved and process improvements were made as a result of the pioneering operations on GB and VX rockets at JACADS and TOCDF.

Recommendation 3-1. The full range of lessons learned from the JACADS and TOCDF experience should be carefully communicated and incorporated into the design and operations of the new baseline incineration system facilities at the Anniston, Umatilla, and Pine Bluff sites.

Finding 3-2. Processing rates for ungelled GB M55 rockets at JACADS and TOCDF were substantially lower than intended in the baseline incineration system design. Jams in the deactivation furnace system (DFS) feed chute and in the heated discharge conveyor, along with failed DFS kiln flange bolts, were the primary causes of poorer performance. Some hardware modifications have been made to address these problems.

Recommendation 3-2. The Army should demonstrate the operability of modified components of the baseline incineration system during initial operational testing at ANCDF and promptly address other problems that arise during disposal processing operations with a view to achieving design production rates while conforming in all respects to permit limitations and safety criteria.

Finding 3-3. The rate for processing gelled GB rockets at TOCDF was limited by a regulatory permit to 1.6 rockets per hour and was further reduced to 1.0 rocket per hour when coprocessing was undertaken. Had the permit limitation not been in force, it is quite likely that a higher rate could have been safely undertaken, but this was not tried.

Recommendation 3-3. The Army, in coordination with state and local government authorities, regulatory agencies, and the larger Anniston area public, should act promptly to demonstrate during the agent trial burns the safety of processing gelled GB M55 rockets at higher rates than were permitted at TOCDF.

Finding 3-4. Flue gas emission tests made during trial burn operations at JACADS and TOCDF for ungelled GB M55 rockets showed higher levels of lead than permitted. Emission levels of other metals and substances of potential concern (SOPCs) met all applicable standards. Dioxins, furans, and polychlorinated biphenyl emission levels were particularly low. The new pollution abatement system carbon filter system was not in place for any of these tests, but it has been incorporated for use in the new baseline facilities at Anniston, Umatilla, and Pine Bluff and should protect further against releases of agents, metals, and SOPCs. This conclusion is reinforced by the surrogate trial burn experience at ANCDF. From a technical point of view, engineering controls should reduce these emissions below levels of concern; however, in view of societal concerns, the committee continues to believe that more frequent monitoring of stack gases for key metals and SOPCs could help to allay public concerns about emissions.

Recommendation 3-4. More frequent monitoring of stack gases for key metals and SOPCs will ensure that the PAS/PFS is operating as expected and may help to allay public concerns about emissions; therefore the Army is urged to analyze the stack gases for key metals and SOPCs more frequently than is now the practice.

Finding 3-5. Gelled GB M55 rockets were safely processed with other GB munitions at TOCDF. This increased the overall rate of destruction of the stockpile at the Tooele site.

Recommendation 3-5. Although the remaining baseline facilities are not expected to have many gelled GB M55 rockets, it is anticipated that coprocessing or complementary processing of GB munitions and containers can be safely accomplished at Anniston. If this turns out to be so, the Anniston experience should be extended to other sites.

> **SOT Element 3.** Assess the potential of the modified proposal to enable the Army to safely accelerate the schedule for disposal of M55 rockets at Anniston.

Finding 4-1. The Anniston stockpile is believed to contain 8,706 gelled GB M55 rockets, the processing of which at the conservatively set TOCDF Resource Conservation and Recovery Act (RCRA) permit rate will extend the disposal schedule and increase the risk to the public from longer storage, which is a greater risk than the risk from disposal. An increase in the authorized processing rate at ANCDF for these munitions is an important feature of the modified disposal plan that has yet to receive regulatory approval.

Recommendation 4-1. The Army should make every effort to obtain regulatory approval of a processing rate for gelled GB M55 rockets that is constrained only by valid requirements for ensuring safety and by equipment capacity limitations. This rate should be established by the results of agent trial burns.

Finding 4-2. For various reasons, the Army's relationship with the public and with county and state officials in the larger Anniston area has been severely strained. This could result in serious delays in the overall disposal schedule, which in turn would extend the storage period and increase the attendant risk.

Recommendation 4-2. The Army should proactively communicate and discuss its basis for establishing a safe processing rate with concerned stakeholders as well as with regulatory authorities.

Finding 4-3a. It appears that a combination of processing segments of gelled GB rockets and complementary processing of other GB munitions with GB rockets could speed up the overall rate of stockpile destruction at ANCDF. This is an important element of the modified disposal plan being put forth by the Army.

Finding 4-3b. The modified disposal plan envisions destruction of the entire GB munitions stockpile prior to VX rocket processing. This change would reduce worker risk since it eliminates one agent changeover and the dangers associated therewith. It would extend the storage period for VX rockets, thus slightly increasing the risk to the public, but would allow processing of the entire stockpile to be completed sooner, partially offsetting storage risk. It would reduce homeland security concerns by earlier elimination of all of the chemical agents in storage at ANCDF.

Recommendation 4-3. The Army, with proactive attention to public input, should seek approval of the modified disposal plan for ANCDF and, upon gaining regulatory approval, implement it without delay to minimize the risks associated with continued storage.

Finding 4-4. The approach of Continental Research and Engineering in modeling the performance of the DFS operating on gelled GB M55 rocket segments necessarily simplified the process mechanisms involved. The committee believes that processing 34 rockets per hour is very optimistic. Processing 1 gelled rocket per hour at TOCDF showed pressure spikes (within design limits) that were probably associated with rapid combustion of the rockets in the first part of the kiln. An additional concern is that the DFS may not have time to cool sufficiently between rocket injections at higher throughput rates. Another concern is that gelled agent may begin to burn in the feed chute and overheat it. Still another is that transient pressure puffs may occur. Also, there was no prior field demonstration at TOCDF that gelled GB M55 rockets can be processed faster than the TOCDF RCRA-permitted rate of 1.6 per hour. While there is the possibility that dumping individual sheared rocket parts, as few as one at a time, into the DFS might result in more uniform, effective, and controlled combustion within the kiln and fewer automatic waste feed cutoffs, the effects of additional cycling on the chute gates must also be taken into account.

Recommendation 4-4. The committee recommends that the Army proceed with design and schedule work for processing gelled GB M55 rockets at the rate of 9.2 per hour, which is equivalent to having one rocket in the DFS kiln at any one time, with the proviso that modeling work continue and appropriate trial burns be conducted. The Army might consider dumping sheared rocket parts into the DFS one at a time to determine if this will improve kiln operations and have a positive impact on automatic waste feed cutoffs. When the first trial burn with gelled agent munitions occurs, the operators should carefully and slowly increase the feed rate from the 1.6 rockets per hour permitted at TOCDF up to the design rate of 9.2 rockets per hour or higher, if permitted by regulatory authorities and other Alabama officials. In addition to continuous monitoring of the agent destruction and removal efficiency, the emissions from the stack, and the Process Data and Recording System data, a continuous record should be taken of differential pressures, along with DFS kiln and feed chute gas and metal temperatures. Regulatory approval should be sought for the maximum feed rate that can be shown by agent trial burn data to be safe for the public, workers, and the environment.

> **SOT Element 4.** Assess the risk and hazard analyses associated with the original and modified proposals for M55 rocket disposal at Anniston for implications concerning potential effects on workers and the general public.

Finding 4-5. The risk of fatalities to workers and the public posed by agent exposure is somewhat lower for the modified disposal plan than if gelled GB M55 rockets at Anniston were to be processed at the TOCDF rate of 1.6 rockets per hour, because the stockpile would be destroyed a year sooner, thus reducing storage risk. In either plan, however, the calculated risk is very low. Further, if the total duration of stockpile destruction can be reduced, there will be fewer hours of exposure to storage risk and the community will be safer. Similarly, worker safety is also improved by fewer hours of operation.

Recommendation 4-5. The Army should improve on its attempts to promote public understanding of the nature and magnitude of risks associated with the existence of the stockpile and the role of the stockpile destruction program in reducing and ultimately eliminating the risk. Risk reduction options should be communicated clearly to interested stakeholders for input and feedback.

Finding 4-6. The health risk assessment for ANCDF, which defines the health risks associated with various emissions, is not yet available, but based on trial burn data for destroying rockets at JACADS and TOCDF, it is likely that the emissions will meet all standards. This is further supported by results of the surrogate trial burns at ANCDF.

Recommendation 4-6. The health risk assessment for ANCDF should be completed as rapidly as possible and the results communicated to workers, the public, and elected officials.

Finding 4-7. Because of the much smaller numbers of gelled rockets estimated to be stored at Umatilla and Pine Bluff, the modified disposal plan process developed for Anniston may not be needed at those sites. Delays associated with permit modification to allow a higher processing rate may exceed the delay associated with processing at the slower TOCDF RCRA-permitted rate.

Recommendation 4-7. The Army should proceed at Umatilla and Pine Bluff based on the existing RCRA permit applications.

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Appendixes

Appendix A

NRC Recommendations on Public Involvement Reprinted from 2000 Report

The NRC's Committee on Review and Evaluation of the Army Stockpile Disposal Program (Stockpile Committee) has provided technical advice and counsel to the Army on aspects of chemical stockpile disposal since the beginning of the Chemical Stockpile Disposal Program (CSDP) in the mid-1980s. Over the course of the developments within the CSDP in the ensuing years, the importance of communicating with the public, and where possible, involving interested stakeholders in decision making on matters of local concern regarding the CSDP has been apparent. Indeed, early in the CSDP, Citizen Advisory Commissions (CACs) were established in each of the eight states holding a portion of the chemical stockpile in the continental United States. Members are appointed by the respective governors. Collectively, these commissions serve as a formal mechanism to facilitate communication between local communities and the Army.

As the CSDP has evolved and disposal facilities have been constructed and become operational, so too have the Army's efforts in public relations, public outreach, and public involvement. During this time, the Stockpile Committee has consistently encouraged a commitment by the Army to pursue these efforts, and through its reports it has offered specific findings and recommendations. The most recent NRC report to have been entirely directed to the Army's public affairs activities for the CSDP was *A Review of the Army's Public Affairs Efforts in Support of the Chemical Stockpile Disposal Program*, published in 2000 (NRC, 2000). The recommendations from that report are reprinted below to illustrate the proactive communication recommended in Recommendation 4-2 of the current report. Since the publication of the 2000 report, the Army has responded in varying degrees to these recommendations.

Recommendation 1. The mission and vision statements for the Public Outreach and Information Office (POIO) should describe how the role of POIO relates to and supports the mission of the Chemical Stockpile Disposal Program. The mission and vision statements should differentiate between the roles of public relations, public outreach, and public involvement. CSDP as a whole would benefit by explicitly considering how POIO's effectiveness could be enhanced in conjunction with CSDP's operations.

Recommendation 2. The Public Outreach and Information Office (POIO) in the Chemical Stockpile Disposal Program (CSDP) should establish specific, measurable objectives and evaluate its organizational strategy in terms of those objectives. This will require that the Program Manager for Chemical Demilitarization integrate POIO's activities into the overall program and provide appropriate support from line management. Outcomes should be evaluated in terms of the defined objectives.

Recommendation 3. The Program Manager for Chemical Demilitarization should reevaluate the level and priority of resource allocations necessary to maintain support for the Public Outreach and Information Office as scheduled disposal operations are undertaken at more sites and as the scope of CSDP activities expands. This reevaluation should include monitoring the use and effectiveness of the staff and CSDP's outreach methods, as well as incorporating POIO miscues and accomplishments into the lessons-learned program. Lessons learned from program evaluations should then be reflected in the mission statement, measurable objectives, and resource allocations.

Recommendation 4. The Stockpile Committee strongly supports the continued development by the Public Outreach and Information Office (POIO) of well-coordinated strategic and tactical documents for planning and operations, including Tier 3 documents for all sites. The public affairs planning and strategy process, including documents supporting the process as well as the training of employees, should be carefully monitored and evaluated. POIO's responses to unanticipated events and the subsequent dissemination of information should be carefully planned, practiced, and evaluated. Findings from evaluations and exercises should be introduced into the lessons-learned process.

Recommendation 5a. The Program Manager for Chemical Demilitarization should continue to reach out to stakeholders via multiple public relations, public outreach, and public involvement methods, track the success of these methods, and evaluate the information obtained from them. The 1999 CSDP survey of all sites should be followed up with focused information gathering to clarify key unresolved issues.

Recommendation 5b. The Program Manager for Chemical Demilitarization should use a variety of methods in a focused effort to solicit the views, values, and needs of stakeholders on closures and future uses of stockpile disposal sites.

Recommendation 5c. The Army should clarify its policy on funding outside experts to assist citizens advisory commissions (CACs). To ensure that CACs are credible representatives of the public interest that can be relied upon to monitor PMCD activities, providing technical assistance might be appropriate in certain circumstances.

Recommendation 5d. Citizens advisory commissions should be encouraged to identify specific objectives and issues they wish to resolve with the Army.

Recommendation 5e. The Web site of the Program Manager for Chemical Demilitarization should be improved and expanded to provide information consistent with the objectives of the Public Outreach and Information Office.

Recommendation 6. The Public Outreach and Information Office (POIO) should continue to pursue a multidirectional lessons-learned program that includes a tracking system for gathering data from one-way communications and public outreach efforts, surveys, and informal and formal meetings with stakeholders. POIO should also continue to reach out to other governmental and nongovernmental organizations (such as the American Chemical Council) to explore innovative ideas with analogous programs.

Recommendation 7a. The Program Manager for Chemical Demilitarization should focus on increasing meaningful public input into the decision-making process in order to build a cadre of stakeholder leaders who are trusted by the community to monitor the Chemical Stockpile Disposal Program. These leaders are likely to include, but are not limited to, local mayors, health officers or their equivalents, environmental commissioners, journalists, educators, and other local leaders.

Recommendation 7b. The Program Manager for Chemical Demilitarization should execute memoranda of agreement, as necessary, with other government agencies to create responsible partnerships that clearly define the lines of authority. Because many agencies are involved, many conflicting views will have to be resolved to ensure effective coordination.

Recommendation 8. The Public Outreach and Information Office should define its critical role in decisions related to site closure and future use in addition to its current role in the disposal of chemical agents and munitions. Its role should be defined in the context of the CSDP's overall strategy for dealing with these issues.

REFERENCE

NRC. 2000. A Review of the Army's Public Affairs Efforts in Support of the Chemical Stockpile Disposal Program. Washington, D.C.: National Academy Press.

Appendix B

ANCDF Campaign Schedule Options

Table B-1 (p. 50) shows the order and duration (in days) for each planned disposal campaign at the Anniston Chemical Agent Disposal Facility (ANCDF) for all of the munitions stored at Anniston Army Depot according to four schedules. This table was developed by Science Applications International Corporation (SAIC), an Army contractor. The first schedule is the original plan proposed for ANCDF before the presence of gelled GB rockets at Anniston was discovered. The second schedule retains the original order of disposal campaigns and changeovers but assumes a processing rate of 9.2 gelled GB M55 rockets per hour.

Schedules three and four are variations of the ANCDF modified plan. These schedules provide for coprocessing or complementary processing of other munitions while gelled GB M55 rockets are processed. The modified plan also has fewer changeover periods since all the GB is processed before munitions or containers of VX nerve agent or mustard agent are processed. The first schedule under the modified plan provides for a processing rate of 9.2 gelled GB rockets per hour, whereas the second schedule indicates the number of days necessary for each campaign if processing of the gelled GB rockets at Anniston is restricted to the permitted rate of 1.6 rockets per hour that was used at TOCDF.

TABLE B-1 ANCDF Campaign Schedule Options

Original Schedule	Original Schedule Duration (days)	Duration at Projected Gelled Rate (days)	Modified Schedule	Modified Schedule Duration at Projected Gelled Rate (days)	Alternative Duration—TOCDF Gelled Rate (days)
	GB Gelled Rocket Processing Rate (per hour)			GB Gelled Rocket Processing Rate (per hour)	
	Not Available	9.2		9.2	1.6
Operations start	19 Sep 02	19 Sep 02	Operations start	19 Sep 02	19 Sep 02
GB M55	390	474	GB M55	175	175
Agent changeover	132	139	GB M55, GB 8-in.	152	152
VX M55	150	150	GB M55	42	42
Changeover	64	64	GB M55, GB 155-mm	56	56
VX 155-mm	271	271	GB M55	42	42
Changeover	49	49	GB M55, GB 105-mm	48	127
VX mine	166	166	GB M55	79	463
Agent changeover	136	136	**Agent changeover**	139	139
GB 8-in.	79	79	VX M55	150	150
Changeover	42	42	Changeover	59	59
GB 155-mm	26	26	VX 155-mm	285	285
Changeover	42	42	Changeover	58	58
GB 105-mm	108	108	VX mine	166	166
Agent changeove	137	143	**Agent changeove**	143	143
HD/HT 4.2-in.	458	458	HD/HT 4.2-in.	467	467
Changeover	19	19	Changeover	19	19
HD ton container	30	30	HD ton container	30	30
Changeover	42	42	Changeover	42	42
HD 105-mm	53	53	HD 105-mm	43	43
Changeover	42	42	Changeover	42	42
HD 155-mm	99	99	HD 155-mm	74	74
Operations end	27 Aug 09	2 Dec 09	Operations end	18 Jan 09	23 Apr 10
Total duration	6.9 years	7.2 years	Total duration	6.3 years	7.6 years

Source: Adapted from SAIC, 2002, Risk Management Analysis: Effect of Gelled Rocket Processing Schedule Changes on Storage Risk and ANCA, August 9, Abingdon, Md.: SAIC.

Appendix C

Biographical Sketches of Committee Members

James F. Mathis, *Chair*, is a member of the National Academy of Engineering and graduated from the University of Wisconsin with a Ph.D. in chemical engineering. Dr. Mathis was vice president of science and technology for Exxon Corporation, where he was responsible for oversight of $700 million in worldwide research and development programs, and chair of the New Jersey Commission on Science and Technology until his retirement in 1997.

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

John J. Costolnick graduated from Northwestern University with an M.S. degree in chemical engineering and is a registered professional engineer. He retired as vice president for engineering at Exxon Chemical Company. He worked for Exxon for more than 35 years, serving in positions of increasing responsibility, from manufacturing manager and plant manager, to vice president for agricultural chemicals and vice president for basic chemical technology. Mr. Costolnick has considerable experience in chemical operations and manufacturing.

Elisabeth M. Drake, a member of the National Academy of Engineering, graduated from Massachusetts Institute of Technology (MIT) with a Ph.D. in chemical engineering. She retired in 2000 as the associate director of the MIT Energy Laboratory. She has had considerable experience in risk management and communication, in technology associated with the transport, processing, storage, and disposal of hazardous materials, and in chemical engineering process design and control systems. Dr. Drake also served on several National Research Council committees relating to chemical demilitarization. Dr. Drake has a special interest in the interactions between technology and the environment. She belongs to a number of environmental organizations, including the Audubon Society, the Sierra Club, and the National Wildlife Federation.

Deborah L. Grubbe graduated from Purdue University with a B.S. in chemical engineering with highest distinction and received a Winston Churchill Fellowship to attend Cambridge University in England, where she received a certificate of postgraduate study in chemical engineering. She is a registered professional engineer and engineer of record for DuPont. She is currently corporate director for safety and health at DuPont. Previously, she was operations and engineering director for DuPont Nonwovens, accountable for manufacturing, engineering, safety, environmental, and information systems. Ms. Grubbe is a board member of the American Institute of Chemical Engineers, Engineering and Construction Contracting Division, and has held committee leadership positions with the Construction Industry Institute. She has considerable expertise in safety, chemical manufacturing technology, and project management and execution.

David A. Hoecke graduated from Cooper Union with a B.S.M.E. He is currently president and CEO of Enercon Systems, Inc. His expertise is in the fields of waste combustion, pyrolysis, heat transfer CFD modeling, and gas cleaning. In 1960, he began working for Midland-Ross Corporation as a project engineer, rising to chief engineer for incineration by 1972. In 1974, he founded his own company and has since been responsible for the design and construction of numerous combustion systems, including solid waste incinerators, thermal oxidizers, heat recovery systems, and gas-to-air heat exchangers. His hands-on experience gives him the expertise needed to participate in the assessment of the incineration technologies employed by the Army.

David H. Johnson graduated from Massachusetts Institute of Technology with a Sc.D. in nuclear engineering. He currently serves as vice president and general manager of ABS Consulting in Irvine, California. He has more than 20 years experience in risk-based analysis for industry and government applications. He has considerable expertise and knowledge in all facets of probabilistic risk assessments, including probabilistic modeling and investigation of the impacts of industrial endeavors. His primary expertise is in risk assessment and management.

Peter B. Lederman graduated with a Ph.D. in chemical engineering from the University of Michigan. He recently retired as executive director, Hazardous Substance Management Research Center, and executive director, Office of Intellectual Property, New Jersey Institute of Technology. Dr. Lederman has over 50 years of broad experience in all facets of environmental management, control, and policy development; considerable experience in hazardous substance treatment and management; and over 18 years of experience as an educator. He is a registered professional engineer, a diplomate in environmental engineering, and a national associate of the National Academies. Dr. Lederman has also worked at the federal (EPA) and state levels, with particular emphasis on environmental policy. His expertise is in chemical engineering, hazardous waste treatment, and educational and corporate leadership.

John L. Margrave, a member of the National Academy of Sciences, graduated from the University of Kansas with a B.S. in engineering physics and a Ph.D. in physical chemistry. Dr. Margrave is currently the chief scientific officer at the Houston Advanced Research Center and the E.D. Butcher Professor of Chemistry at Rice University. His expertise is in high-temperature chemistry, materials science, and environmental chemistry. His research interests include various areas of physical and inorganic chemistry, including matrix-isolation spectroscopy/metal atom chemistry; high-temperature chemistry, including mass spectrometry; high-pressure chemistry; environmental chemistry; and nanoscience/technology. Dr. Margrave also served on a National Research Council committee that completed a study in the chemical demilitarization area.

Charles I. McGinnis, who has an M.Engr. in civil engineering from Texas A&M University, retired from the U.S. Army as a major general and former director of civil works for the U.S. Army Corps of Engineers. More recently, he served in senior positions at the Construction Industry Institute in Austin, Texas. He has also served as director of engineering and construction for the Panama Canal Company and later as vice president of the company and lieutenant governor of the Canal Zone. As director of civil works, he was responsible for a $3 billion per year planning, design, construction, operation, and maintenance program of water-resource-oriented public works on a nationwide basis. He has considerable experience with engineering and construction. He is a registered professional engineer in Texas and Missouri.

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

Jeffrey I. Steinfeld graduated from Harvard University with a Ph.D. in physical chemistry. He is currently professor of chemistry at Massachusetts Institute of Technology. He has taught and written extensively for 37 years at MIT, specializing in high-sensitivity monitoring techniques, pollution prevention, and environmental research and education. He is well suited to serve on a committee that is concerned with the safety and monitoring activities of the Army's chemical disposal program. His interest and experience in bringing scientific knowledge into environmental decision making via stakeholder involvement can be particularly applicable to assessment of disposal program activities that have considerable political, economic, social, scientific, and technical impact.