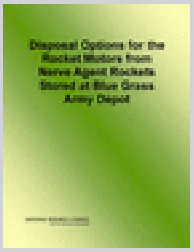

Disposal Options for the Rocket Motors From Nerve Agent Rockets Stored at Blue Grass Army Depot

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THE NATIONAL ACADEMIES
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Division on Engineering and Physical Sciences

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Preface

The Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP), under the management of the Program Executive Officer for Assembled Chemical Weapons Alternatives (PEO ACWA), is responsible for destroying the chemical weapons stockpiles currently being stored at the Blue Grass Army Depot (BGAD) and the Pueblo Chemical Depot. The BGAD stockpile consists of 523 tons of mustard agent loaded in projectiles and nerve agents GB and VX loaded in both projectiles and rockets. The rocket portion of the stockpile at BGAD consists of approximately 70,000 M55 rockets. BGCAPP will destroy the M55 rockets in a process where the first step will be to cut the rocket and separate it into the rocket warhead and the rocket motor. The rocket warhead will be destroyed at BGCAPP by chemical neutralization followed by supercritical water oxidation. Although the BGCAPP facility will have the capability for destroying an entire M55 rocket, owing to a design change in the mid-2000s the separated rocket motors will be disposed of at a place other than BGCAPP.

Disposing of the separated rocket motors outside of BGCAPP presents some unique safety and environmental challenges, so the PEO ACWA asked the National Research Council (NRC) to conduct a study to offer guidance on technologies and options for the disposal of the separated rocket motors. The committee that was assembled by the NRC held a number of meetings, a virtual meeting, and teleconferences. It also visited the BGCAPP project offices in Richmond, Kentucky.

The focus of this report is on the potential sites and technologies that might be used to dispose of the separated rocket motors outside of BGCAPP. These options include treatment and disposal on-site at BGAD or off-site at a commercial or governmental facility. Potential technologies, primarily thermal and chemical, that could be used to dispose of the separated rocket motors are discussed. The report also addresses safety, storage, throughput, and transportation.

As chair of this committee, I want to express my sincere thanks to the members of the committee for their work on this report. Their expertise in energetics as well as their experience with the safe disposal of conventional munitions was invaluable in addressing the statement of task. I would also like to thank James Myska, senior research associate at the Board on Army Science and Technology, and Bruce Braun, director of the Board on Army Science and Technology, for their contributions in running this study. Mr. Myska did an outstanding job on this project. He mastered the subject matter, kept the committee focused on the statement of task, and ensured that the writing was concise and accomplished in a timely manner. Lastly, I want to thank Deanna Sparger for her invaluable administrative and research support to the committee.

Randal J. Keller, *Chair*
Committee on Disposal
Options for the Rocket Motors
of Nerve Agent Rockets at
Blue Grass Army Depot

Acknowledgments

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 National Research Council's (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:

Ruth Doherty, Naval Surface Warfare Center,
Rebecca Haffenden, Argonne National Laboratory,
Jeffrey L. Lee, U.S. Army Research, Development and Engineering Command,
Hyla Napadensky, Independent Consultant,
James Neidert, U.S. Army Aviation and Missile Development and Engineering Center,
Carol A. Palmiotto, E.I. du Pont de Nemours & Company,
Stanley Sandler (NAE), University of Delaware,
Leonard Siegel, Center for Public Environmental Oversight, and
Stefan Thynell, Pennsylvania State University.

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 Royce W. Murray (NAS). Appointed by the National Research Council, he 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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Abbreviations and Acronyms

BGAD	Blue Grass Army Depot
BGCAPP	Blue Grass Chemical Agent Disposal Pilot Plant
CAC	Citizens' Advisory Commission
CDCAB	Chemical Destruction Community Advisory Board
DAVINCH	Detonation of Ammunition in a Vacuum Integrated Chamber
DoD	Department of Defense
EDS	explosive destruction system
EDT	explosive destruction technology
EONC	enhanced on-site container
EPA	Environmental Protection Agency
ESD	electrostatic discharge
GB	a nerve agent, also known as sarin
GPL	general population limit
HAWG	hazards analysis working group
HERO	hazards of electromagnetic radiation to ordnance
KAR	Kentucky Administrative Rules
KDEP	Kentucky Department for Environmental Protection
KRS	Kentucky Revised Statutes
MPPEH	materials potentially presenting an explosive hazard
PCB	polychlorinated biphenyl
PEO ACWA	Program Executive Officer for Assembled Chemical Weapons Alternatives
POP	performance oriented packaging
RCRA	Resource Conservation and Recovery Act
SCWO	supercritical water oxidation
SDC	Static Detonation Chamber, manufactured by Dynasafe AB
SFT	shipping and firing tube
SOP	standard operating procedure
STEL	short-term exposure limit
TSCA	Toxic Substances Control Act
VX	a nerve agent

Summary

This report responds to a request by the Program Executive Officer for Assembled Chemical Weapons Alternatives (PEO ACWA) that the National Research Council examine and evaluate options for disposal of the motors that will be separated from approximately 70,000 M55 rockets stored at the Blue Grass Army Depot (BGAD) that are not contaminated by the chemical nerve agent contained in the rocket warheads. The Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) will be responsible for destroying the chemical weapons stockpile currently being stored at BGAD. BGCAPP was designed to separate M55 rockets into warhead and motor sections and process the chemical agent warhead portion. However, BGCAPP is not designed to dispose of all of the separated rocket motors.[1] This report evaluates the potential technologies and options that could be used to dispose of the separated rocket motors at a location other than BGCAPP: either on-site (at BGAD) or off-site (away from BGAD).

It is important to note that, as per the statement of task, this report deals solely with separated rocket motors that will have been monitored to ensure there is no agent present above the short term exposure limit and cleared for transportation and disposal off-site. Any separated rocket motors that are determined to be contaminated by agent above the short-term exposure limit will be processed at BGCAPP. In this summary, the committee presents what it believes are its most significant findings and recommendations.

The committee was composed largely of members with expertise in the destruction of conventional munitions. Accordingly, much of this report addresses the safety risks that must be taken into account when handling and disposing of the separated rocket motors. There are numerous safety risks that can impact the disposal of the separated rocket motors because they contain aged and degraded energetic materials, specifically the M28 propellant. The M55 rockets were manufactured between 1961 and 1965, meaning that the M28 propellant was between 47 and 51 years old when this report was prepared. Due to aging and degradation, the M28 propellant may have become more sensitive to shock and thermal conditions. The separated rocket motors will also be more exposed to environmental conditions, such as heat and humidity, than they were as part of an assembled rocket. This could accelerate propellant degradation and increase the safety risks. Measures can be taken, however, to address the risk of accelerated propellant degradation, among them using desiccant to control humidity and designing storage boxes so that heat dissipation is adequate. In any case, the committee believes that the separated rocket motors should be disposed of as soon as possible after rocket cutting.

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[1] The term *separated rocket motor*, as the committee uses it, is defined in Appendix A.

The M55 rockets were designed at a time when the electromagnetic environment was quite different from what it is today—for example, wireless devices such as cell phones had not yet been invented. The committee believes the process of cutting the rocket creates a new motor configuration and could damage its electrical system, leaving it susceptible to risks from electromagnetic emanations and electrostatic discharge. The committee stressed that approved practices and procedures for safely handling energetic materials need to be followed and that potential new safety risks need to be evaluated. The committee also noted that the M28 propellant contains substances such as lead that could pose a safety hazard depending on the destruction technology selected and how that technology is implemented. The committee believes that a hazards analysis working group would be an important tool to address the multiple safety concerns associated with separated rocket motors.

Finding 2-2. The Army's 2002 M55 Rocket Assessment Summary Report for the intact M55 rocket may not be directly applicable to the separated rocket motors. New not-readily-apparent safety risks could emerge during demilitarization operations involving the M55 rocket containing energetic materials.

Finding 2-5. The current hazards to the separated rocket motors posed by electromagnetic radiation and the potential for electrostatic discharge may require verifying the condition of the igniter system after cutting before placement in the storage and shipping box.

Finding 2-3. Among the vitally important approved safety practices and procedures that need to be followed in handling energetic materials are the assessment and approval of standard operating procedures and hazard analyses. They will account for potential new safety risks that emerge during the demilitarization process.

Recommendation 2-3. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should establish a hazards analysis working group to assess, analyze, and develop risk mitigation practices and procedures with specific attention to energetic materials in the overall demilitarization of the M55 rocket.

In addition to reviewing disposal technologies and options, the committee was asked to examine the feasibility of recycling options for the M28 propellant. The committee concluded that recycling these aged and degraded energetic materials was not feasible based upon similar experience with conventional munitions. The committee did find that the recycling of the metal components should be considered, provided that any recycler takes appropriate precautions against lead exposure.

Finding 3-1. There are no practical, useful, or cost-effective means of recycling energetic materials from the M28 propellant.

Finding 3-2. It is feasible to recycle the metal components of the separated rocket motors.

Recommendation 3-1. The Blue Grass Chemical Agent-Destruction Pilot Plant program staff should inform the recipient of materials for recycling of the potential for the presence of lead or lead dust on recovered materials.

A significant portion of this report reviews the current technologies that could be used to dispose of the separated rocket motors. These are primarily open thermal, contained thermal, and chemical treatment options. The committee presents a comparison of advantages and disadvantages of each technology and considers the estimate of separated rocket motor throughput where available. The committee finds that a contained thermal treatment technology is the best option for disposing of the separated rocket motors.

Finding 3-4. Thermal treatment demilitarization and disposal operations performed in a chamber require the least handling and permit treatment of product emissions. Chemical technologies either are not mature or are not readily implementable for the disposal of the separated rocket motors.

Finding 3-7. A contained thermal technology is the best option for disposing of the rocket motors separated from the M55 rockets stored at the Blue Grass Army Depot.

The storage and disposal of the separated rocket motors could both be rate-limiting factors in overall BGCAPP operations. For a variety of reasons, the disposal of the separated rocket motors will likely proceed at a slower rate than the warhead processing at BGCAPP. This necessitates the ability to store some number of separated rocket motors from the time of rocket cutting until eventual disposal. The committee is concerned that the storage space that is included in the BGCAPP design will not be sufficient and that any mishap that interrupts the disposal of the separated rocket motors could easily impact M55 rocket processing at BGCAPP. The committee discusses securing additional storage space for separated rocket motors within the BGAD area, such as converting the storage igloos in which the M55 rockets are currently stored into explosive hazardous waste units.

Finding 4-1. The provision of adequate storage space for the separated rocket motors is important for the overall rate of operations for M55 rocket disposal at the Blue Grass Chemical Agent-Destruction Pilot Plant. Rocket-cutting and warhead-processing operations would need to be slowed or halted if the combination of storage capacity and separated rocket motor disposal could not meet the rate at which separated rocket motors are produced.

Recommendation 4-1. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should secure additional space for storage of separated rocket motors. It is essential that discussion with Blue Grass Army Depot staff concerning the option for securing such additional space at the depot be given high priority.

Finding 4-4. Reusing emptied M55 rocket storage igloos for storage of separated rocket motors is a possible solution to the problem of inadequate storage space. Pursuing this option would entail much coordination and planning and would take time.

Recommendation 4-2. If a decision is made to pursue this option, Blue Grass Chemical Agent-Destruction Pilot Plant program staff should prepare a plan to convert the M55 rocket storage igloos to hazardous waste storage sites that are also site-approved for the storage of explosives. The plan should include management of the transition without the need to submit separate approval requests one igloo at a time.

When considering storage for the separated rocket motors, it should be noted that, owing to environmental and other factors, the storage risk may be greater for separated rocket motors than for an intact M55 rocket. Further, owing to the new configuration of the separated rocket motors, a new storage and transportation box may be required for packaging the separated rocket motors.

Finding 4-5. Storage risk may increase more quickly in the case of separated rocket motors than assembled M55 rockets because of the increased environmental exposure of the separated motors. The effects of this environmental exposure on the separated rocket motors have not been characterized.

Recommendation 4-3. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should dispose of separated rocket motors as soon as possible, using a "first in, first out" protocol to minimize storage time and reduce risk.

It is technologically feasible to dispose of the separated rocket motors on-site (at BGAD). BGAD currently operates an on-site open burn facility for the disposal of conventional munitions and has an operational (though not currently operating) D-100 detonation chamber for the same purpose. Either of these could be adapted for the disposal of separated rocket motors. It is also possible that other technologies could be established on BGAD to dispose of the separated rocket motors. Key considerations will be public acceptance of the technology chosen, obtaining the necessary permits, and balancing separated rocket motor disposal with the overall BGAD workload. One primary advantage to on-site disposal is that the transportation of the separated rocket motors would likely be much safer than moving them over public roads and simpler as well, since broader federal regulations would not apply because the entire process would take place within the BGAD boundaries. Another on-site disposal option would be the long-term storage of the separated rocket motors until BGCAPP completes all chemical agent disposal operations, meaning the separated rocket motors would be stored for several years if BGCAPP operations proceed as currently planned. The separated rocket motors could then be returned to BGCAPP for disposal at whatever rate BGCAPP could manage. The committee does not consider the last option to be the best approach in light of propellant degradation and storage risk, which are discussed in Chapters 2, 4, and 5.

Finding 5-1. The Blue Grass Army Depot has a permitted, operational open-burning site that might be capable of meeting separated rocket motor disposal requirements.

Finding 5-2. There are alternative disposal technologies to open burning that can be instituted at the Blue Grass Army Depot. However, the use of these alternative technologies would necessitate the inclusion of design, construction, and permitting time into the project schedule.

Finding 5-3. A D-100 detonation chamber is currently operational at the Blue Grass Army Depot to dispose of conventional munitions. It is possible that this could be modified and permitted to dispose of the separated rocket motors. A number of other contained technologies are available from commercial vendors, and it might prove simpler to contract for one of these to be installed than to modify the D-100 and obtain the necessary permit modification.

Finding 5-12. Transporting separated rocket motors solely on-site will be safer and easier to accomplish than transporting separated rocket motors off-site.

The disposal of the separated rocket motors off-site is dependent on several factors, including the identification of an appropriate disposal facility, satisfying the pertinent environmental and transportation regulations, and gaining the acceptance of the public.

Finding 5-6. There are potential technologies for the disposal of the separated rocket motors that could be used concurrently at one or more off-site disposal facilities to meet program requirements and schedule. Off-site disposal would increase flexibility in regard to choice of a specific disposal technology. The Blue Grass Chemical Agent Disposal Pilot Plant program staff would, of course, need to work with any off-site disposal facility to ensure that all relevant environmental regulations, such as the Resource Conservation and Recovery Act and the Toxic Substances Control Act, are complied with.

A key factor in off-site disposal is that the transportation of separated rocket motors off-site would be subject to a greater degree of transportation regulation than on-site transportation and would necessitate the design, approval, and procurement of performance-oriented packaging in which to transport the separated rocket motors.

Finding 5-14. Transportation of separated rocket motors off-site must comply with federal regulations governing the transportation of hazardous materials on public thoroughfares, including the use of labeled performance-oriented packaging, which is packaging that has been tested to meet anticipated environmental and transportation stresses.

Finding 5-13. All off-site disposal options necessarily require removal of the separated rocket motors from government property and transportation on public roads or railways. There are numerous federal, state, and Army regulations governing the transportation of explosive hazardous waste, permits, and safety standards that must be met.

Finally, public sentiment and acceptance will be a significant factor in the ability to implement any technology to dispose of the separated rocket motors, as well in the decision whether to dispose of the separated rocket motors on-site or off-site. There is a long-standing, interested, and very knowledgeable community living and working around BGAD. This community has successfully influenced program choices regarding BGCAPP in the past and can be expected to continue to do so. Thus, while not explicit in the committee's statement of task, issues of public sentiment warrant some mention in the report.

1
Introduction

The Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP), under the management of the Program Executive Officer for Assembled Chemical Weapons Alternatives, is responsible for destroying the chemical weapons stockpile currently being stored at the Blue Grass Army Depot (BGAD). BGCAPP and a facility being built at the Pueblo Chemical Depot to dispose of the chemical agent stored there are parts of the nation's effort to destroy its chemical agent stockpile in line with its obligations under the Chemical Weapons Convention treaty. The stockpile stored at BGAD consists of 523 tons of mustard agent in projectiles and nerve agents GB and VX in projectiles and rockets. The chemical agent loads in the weapons will be destroyed by chemical neutralization.[1] In the neutralization process, the munitions are disassembled, the agents and energetic materials are separated, and the agents are neutralized with caustic (for GB, VX, and energetic materials, such as bursters) or water (for mustard agent), producing effluents called hydrolysates. The hydrolysates will be further treated with supercritical water oxidation (SCWO), which uses water at very high temperature (1200°F) and pressure (3,400 psi).

The rocket portion of the stockpile at BGAD consists of about 70,000 M55 rockets, manufactured in 1961–1965, that contain the cholinesterase-inhibiting nerve agents GB and VX (CMA, 2008). Those agents are organophosphates that are capable of binding the enzyme acetylcholinesterase, which breaks down the neurotransmitter acetylcholine in the neural synapses. When acetylcholinesterase is inhibited, the parasympathetic nervous system is overstimulated by excess acetylcholine, resulting in potentially fatal cholinergic effects. GB is the more volatile of the two agents, and its primary mode of exposure is through the respiratory system; VX is absorbed primarily through skin. The two materials are toxic at very low concentrations. Table 1-1 lists time-weighted average maximum recommended exposure levels for the agents. The short-term exposure level (STEL) is designed to protect employees, and the general population limit (GPL) is designed to protect the community at large. Safe-handling procedures for chemical agent weapons are in Volume 6 of Department of the Army Pamphlet 385–61 (U.S. Army, 2008).

The M55 rockets stored at BGAD will be disposed of in a manner entirely different from that used at the other chemical agent disposal facilities that disposed of M55 rockets. At the other facilities, an entire M55 rocket was cut into pieces and processed through incinerators, but the rockets stored at BGAD will be processed as follows. Pallets of M55 rockets will be transported from their BGAD storage igloos in an enhanced on-site container (EONC), received in the unpack area, and monitored for the

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[1] The term *hydrolysis* is used in the chemical demilitarization program.

presence of chemical agent. If chemical agent is detected, the sealed EONC will be opened in the explosive containment vestibule by workers in protective gear, who will overpack any leaking or contaminated rockets; the remaining rockets will proceed to the normal rocket destruction process. If no agent is detected, the rockets will be unpacked from the EONC and placed into the automated rocket handling system (Schlatter, 2010). From that point on, all operations to destroy the agent and warhead bodies will be remotely controlled.

Table 1-1 Time-Weighted Average Maximum Exposure Limits (µg/m^3)

	Time Basis	GB	VX
GPL	24 hours	0.001	0.0006
STEL	15 minutes	0.1	0.01

SOURCE: U.S Army, 2008.

Figure 1-1 is a basic depiction of an M55 rocket in its shipping and firing tube (SFT) and where it will be cut during processing. Figure 1-2 shows a cutaway model of an M55 rocket in flight configuration with fins deployed. The first step in processing the rockets will be for the rocket cutting machine (which works by pressing a rolling blade first against the SFT and then against the rocket body) to cut the fiberglass SFT into two pieces. The forward piece of SFT covering the warhead will be removed, conveyed to the motor shipping room, and placed in a crate. The rocket cutting machine will then make a second cut at the threaded connection between the warhead and the rocket motor. The intact warhead containing the chemical agent, burster, and fuze will be destroyed at BGCAPP by neutralization followed by supercritical water oxidation, as discussed above.

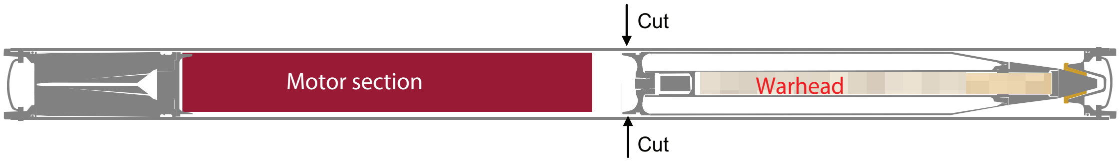

FIGURE 1-1 Simplified diagram of an M55 rocket in its shipping and firing tube, showing where the tube and rocket will be cut. SOURCE: Ron Hawley, Plant General Manager, Bechtel Parsons Blue Grass Team, "Rocket Processing," presentation to the committee, March 20, 2012.

FIGURE 1-2 Cutaway depiction of an M55 rocket in flight configuration with fins deployed. SOURCE: Adapted from CMA, 2008.

The separated rear section of the M55 rocket—containing the M28 rocket propellant, igniter, rocket nozzle, fins and other components—and the fore closure still in its portion of the SFT will be loaded cut side up into a plywood shipping box designed to hold 30 rocket motors. In this report, the term *separated rocket motor* will refer to the separated rear section of the M55 rocket (see definition in Appendix A). Figure 1-3 shows a simplified layout of a separated rocket motor. Peak processing rates are projected to be 20 GB-filled or 24 VX-filled M55 rockets per hour; the process will produce like numbers of separated rocket motors each hour.[2]

The storage boxes containing the separated rocket motors will be placed into an airlock, and the headspace above the motors will be monitored for the presence of any chemical agent above the STEL before being released to the motor packing room and later transportation and disposal. If any agent is detected, the individual separated rocket motors will be manually monitored to determine which ones are contaminated with chemical agent, and entire separated rocket motors that are contaminated will be processed through BGCAPP. This report addresses only separated rocket motors that have been monitored and cleared for disposal either on-site (on BGAD) or off-site (off BGAD). The current plan is to dispose of separated rocket motors outside the BGCAPP facility. The process for clearing the separated rocket motors has yet to be developed and will, of course, need to be negotiated with the Kentucky Department for Environmental Protection.

The BGCAPP facility currently under construction will have the capability of demilitarizing and destroying an entire M55 rocket. Indeed, the original design of the facility included the disposal of the entire M55 rocket in the facility with 18 energetic batch hydrolyzers. As part of a cost-reduction initiative, a decision was made to eliminate all but three of the energetic batch hydrolyzers and to dispose of the separated rocket motors outside BGCAPP. The focus of this report is on the potential sites and technologies that might be used to dispose of the separated rocket motors outside BGCAPP. The options include treatment and disposal on-site or off-site at a commercial or government facility.

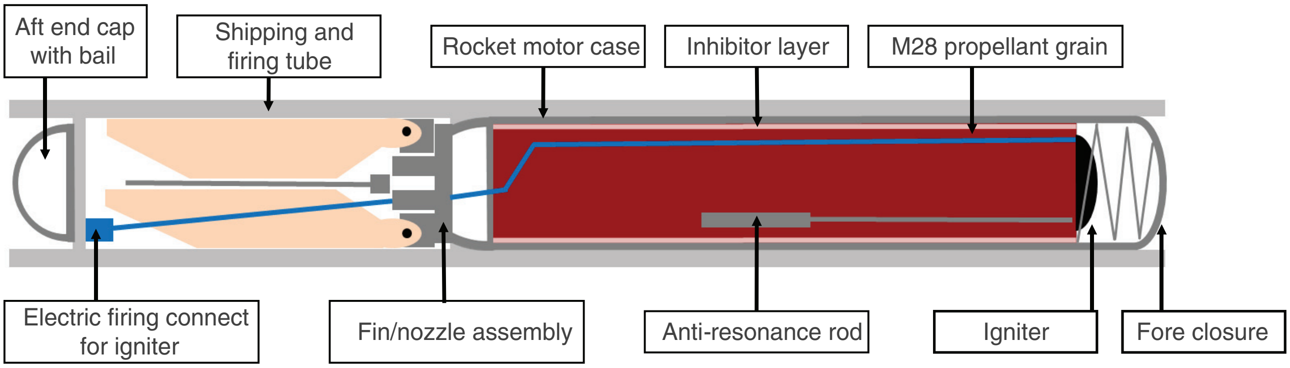

FIGURE 1-3 Simplified layout of a separated rocket motor showing its major components.

BGCAPP has identified the disposal of the separated rocket motors as a potentially rate-limiting factor that could affect the overall rate of M55 rocket disposal at BGCAPP. The main reason is related to storage space at BGCAPP. BGCAPP will have about 1.25 days worth of storage space in the munitions demilitarization building for

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[2] Ron Hawley, plant general manager, Bechtel Parsons Blue Grass Team, “Rocket Processing,” presentation to the committee, March 20, 2012.

separated rocket motors. Any interruption in transportation of rocket motors out of this storage could force a slowing or cessation of M55 rocket processing operations at BGCAPP. Options are needed to address issues of storage, throughput, transportation, and the treatment that will be required to dispose of the roughly 3,350 separated rocket motors that BGCAPP plans to generate each month.[3]

STATEMENT OF TASK

The National Research Council will establish an ad hoc committee to address these specific tasks:

- Investigate off-site and on-site alternative options for disposal of approximately 70,000 M55 rocket motors stored at Blue Grass Army Depot that are not contaminated by chemical nerve agent contained in the rocket warheads
- Review and examine the status of maturity and assess the likelihood of success for each option
- Consider the feasibility of recycling options for the propellant and rocket motor components
- Assess relevant environmental considerations, including those pertaining to the health and safety of workers, and regulatory requirements such as those stemming from applicable Kentucky Revised Statutes and RCRA regulations
- Examine shipping considerations for implementation of off-site alternatives, including packaging requirements

THE COMMITTEE, REPORT SCOPE, AND PROCESS

The committee is composed of persons who have extensive experience in solid rockets, energetic materials, munitions disposal, hazardous wastes, safety, and public involvement. Several committee members have expertise pertinent to the regulations governing the transport and disposal of various types of munitions and associated hazardous materials. Biographies of all the committee members are in Appendix D.

The committee met three times. The first meeting was held in Richmond, Kentucky, and included a briefing from BGCAPP about the options that have been reviewed for the treatment and disposal of the separated rocket motors and committee discussions to begin framing the approach to the study and the report. The second meeting was held in Washington, D.C. where the committee discussed and developed the report draft. The third meeting was also held in Washington, D.C. At this meeting the committee resolved most remaining issues and laid out the path to achieving committee consensus on the report. Committee activities are summarized in Appendix C.

This report reviews various approaches that could be used for safe disposal of the rocket motors separated from the M55 rockets stored at BGAD. It also discusses issues of safety, storage, throughput, transportation of the separated rocket motors, on-site and off-

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[3] Kevin Regan, environmental manager, BGAPP project, “Rocket Motor (RM) Disposal,” briefing to the committee, March 20, 2012.

site disposal options, and how public acceptance could influence the disposal of the separated rocket motors. The coverage of the report begins after the M55 rockets have been cut and the separated rocket motors have been monitored and cleared for transportation and disposal off-site.

OVERVIEW OF REPORT

Chapter 2 focuses on safety—energetics safety, electrical safety, and lead. Although the chemical agent warheads will no longer be present when the separated rocket motors are handled, the separated rocket motors are hazardous in their own right because they contain M28 propellant, which has aged and degraded and will continue to degrade. Explosives safety precautions are necessary in all handling and storage operations that involve the separated rocket motors. Chapter 2 also addresses hazards of electromagnetic radiation to ordnance and risks posed by electrostatic discharge if the igniter leads and shunting are damaged when the rockets are cut.

Chapter 3 is an overview of technologies—primarily chemical and thermal treatment methods—that could be used to dispose of the separated rocket motors. The chapter presents information on both thermal treatment options (open and contained) and chemical treatment options, such as base hydrolysis and supercritical water oxidation. Recycling of the rocket motors is unlikely in that the M28 propellant is old and degraded and contains lead. It would not be practical or cost-effective to reuse the propellant, recover its ingredients, or work it into another form, such as fertilizer. In addition, the SFTs contain polychlorinated biphenyls. The committee envisions that the separated rocket motors will be removed from the SFTs before disposal of the motors, in part to avoid the contamination of disposal waste streams with polychlorinated biphenyls; this is discussed in more depth in Chapter 5. The discussion in Chapter 3 includes recommendations of the technologies that may be best suited for disposal of the separated rocket motors.

The storage of separated rocket motors is discussed in Chapter 4. The storage of the separated rocket motors is a potentially limiting step in M55 rocket disposal at BGCAPP, inasmuch as their disposal will probably proceed at a lower rate than the rocket-cutting operations at BGCAPP. Although the storage of the separated rocket motors is not an explicit item in the statement of task, it is central to the timely processing of M55 rockets through BGCAPP. If the separated rocket motors cannot be transported to a storage or disposal site outside BGCAPP at least as quickly as they are accumulated in BGCAPP, rocket-cutting and warhead-processing operations at BGCAPP would need to be slowed or halted.

Chapter 5 presents some of the specific issues that BGCAPP project management will need to consider when selecting the most appropriate location for disposal of the separated rocket motors. On-site disposal options reviewed by the committee include open burning of the propellant grain at the BGAD permitted explosive hazardous-waste treatment facility; using the D-100 detonation chamber currently operational at BGAD; using alternative technologies, such as explosive destruction technologies, which can be added to BGAD capabilities; and disposal at BGCAPP after completion of all chemical agent destruction operations. Off-site disposal options, in which all the separated rocket motors would be removed from BGCAPP and BGAD and delivered to other facilities for disposal, are also discussed. The chapter considers transportation issues. For example, the transportation of the separated rocket motors on public roads will need to comply with Department of Transportation regulations and will require appropriate and specialized packaging, whereas on-site transportation will have a different, and potentially less demanding, regulatory framework.

The report contains two appendixes that supplement the committee's work in the main body of the report. Appendix A sets forth some definitions that are used specifically by this committee. Appendix B reviews the history of public sentiment as it pertains to the committee's task. Although a consideration of public sentiment is not an explicit item in the statement of task and a rigorous examination of it was beyond the committee's scope, the committee believed that it would be remiss not to include some discussion of it in that it is likely to figure into the ability to implement any given disposal technology or disposal option. Programs for destroying the chemical munitions stockpile managed by the U.S. Army Chemical Materials Agency[4] and the Assembled Chemical Weapons Alternatives[5] program have historically been heavily influenced by public sentiment. The concerns of citizens near BGAD, along potential transportation routes, and near potential off-site disposal locations are therefore going to be important in consideration of any decision about the choice of a technology or option (whether on-site or off-site) to dispose of the separated rocket motors.

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U.S. Army. 2008. Department of the Army Pamphlet 385–61: Toxic Chemical Agent Safety Standards, December 17. Available online at http://www.apd.army.mil/pdffiles/p385_61.pdf. Last accessed June 7, 2012.

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[4] The U.S. Army Chemical Materials Agency has successfully and safely disposed of the chemical agent and munitions stockpiles at Aberdeen, Maryland; Anniston, Alabama; Johnston Atoll; Newport, Indiana; Pine Bluff, Arkansas; Tooele, Utah; and Umatilla, Oregon. Chemical neutralization was used to dispose of bulk agent at Aberdeen, Maryland, and Newport, Indiana. Incineration was used to dispose of the stockpiles at the other sites.

[5] In addition to BGCAPP, a facility is under construction at the Pueblo Chemical Depot, in Colorado, to dispose of the mustard agent stockpile there. The agent will be chemically neutralized by hot-water hydrolysis, and the resulting hydrolysates will be processed through a biotreatment system.

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Safety

As with all chemical and industrial processes, the destruction of the separated rocket motors[1] from the M55 rockets will present inherent safety risks. Working with energetic materials safely requires carefully devised and approved safe operating procedures, processes, and equipment. M55 rockets were manufactured in 1961–1965 (CMA, 2008). The M28 propellant in the rockets was therefore 47–51 years old when this report was prepared. Disposing of the separated rocket motors will require additional consideration given that the M28 propellant includes aged and degraded materials. And the propellant contains lead compounds that must be taken into account in considering disposal options.

A well-designed process for disposal of the separated rocket motors will provide physical safety for the workers controlling or performing the work activities, protect the community and local environment, minimize risks to the physical infrastructure and capital equipment required to perform the work, and produce a manageable waste stream that is minimized to the greatest extent possible. The Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) will use extensive automation to minimize employee exposure to agent and explosive hazards associated with the handling and destruction of M55 rockets in the plant. However, M55 rocket processing in BGCAPP will result in the need to dispose of about 70,000 intact rocket motor assemblies[2] outside BGCAPP. For more information on the important topic of process safety, the reader is referred to NRC, 2011.

ENERGETICS SAFETY ISSUES

Because the rocket motor propellant presents an energetic hazard, explosives safety precautions must be taken in all handling and storage operations. Such operations are governed by Department of Defense (DoD) Ammunition and Explosives Safety Standards (DoD, 2008) and within the Army by the current version of the Army's Ammunition and Explosives Safety Standards (U.S. Army, 2011). Guidance in those two documents must be followed in any treatment program.

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[1] See Appendix A for how the committee defines *separated rocket motor*.

[2] These assemblies include the rocket motor in its steel case, aluminum fins, ignition system and wires, fins and miscellaneous parts, and fore closure—all in the rear half of the shipping and firing tube.

The composition of M28 propellant used in the M55 rocket is listed in Table 2-1. It is a double-base[3] propellant with a lead stearate burn-rate modifier. The propellant is contained within a cellulose acetate inhibitor that has been plasticized with dimethylphthalate. The purpose of the inhibitor is to limit propellant burning along the outer surface of the propellant during motor firing. The hazard classification of the separated rocket motors as determined by following the Department of Defense Ammunition and Explosives Hazard Classification Procedures, TB 700–2 (DoD, 1998), affects the packaging requirements for the rocket motors, the number of rocket motors that may be transported off-site in a given shipment configuration, and the number of rocket motors that may be stored in a given location before disposal. The hazard classification of the assembled M55 rockets in their shipping and firing tubes (SFTs) for storage and transportation is currently 1.2.1, which means that they present a non–mass explosion and fragment-producing hazard. BGCAPP intends to apply for a 1.3 hazard classification, which would mean that they present a mass fire and minor blast or fragmentation hazard, to cover shipping and handling of the separated rocket motors (DoD, 1998).Table 2-2 lays out the hazard classifications that are applied to explosive materials.

Table 2-1 Nominal Composition of M28 Propellant

Component	Weight Percent	Purpose
Nitrocellulose	60	Energy source
Nitroglycerin	23.8	Energetic plasticizer
Triacetin	9.9	Casting solvent
Dimethylphthalate	2.6	Plasticizer
Lead stearate	2.0	Burn-rate modifier
2-Nitrodiphenylamine	1.7	Stabilizer

SOURCE: CMA, 2005.

Table 2-2 Hazard Classifications Applied to Explosive Materials

Hazard Classification	Hazard
1.1	Mass explosion
1.2	Non–mass explosion, fragment-producing
1.3	Mass fire, minor blast, or fragment
1.4	Moderate fire, no blast, or fragment
1.5	Explosive substance, very insensitive (with mass explosion hazard)
1.6	Explosive article, extremely insensitive

SOURCE: DoD, 1998.

Finding 2-1. The hazard classification of the rocket motors has not been determined. The classification will directly affect packaging, transportation, and storage requirements for off-site disposal options.

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[3] The term *double-base* connotes that there are two active constituents in the propellant. In the case of the M28 propellant, they are nitrocellulose and nitroglycerin.

Recommendation 2-1. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should expedite the process required to provide the hazard classification of the separated rocket motors.

The aging and degradation of the M28 propellant could cause it to have increased sensitivity to impact, shock, and thermal conditions. There were four pressure-pulse events when the motors of M55 rockets were cut at the Umatilla Chemical Agent Disposal Facility. There have also been over 20 fires when rocket motors were cut at incineration-based chemical agent disposal facilities (CDC, 2006). Although the separated rocket motors at the Blue Grass Army Depot will not be cut, those incidents indicate some sensitivity of the propellant, which could be a factor in disposing of the separated rocket motors. Because of the potential severity of incidents arising from propellant sensitivities, the Department of Defense (DoD, 2008) and the Department of Transportation (49 CFR 173.56) have instituted policies for handling these types of materials.

Nitrate esters, such as the nitrocellulose in the M28 propellant, degrade slowly and liberate nitrogen dioxide (NO_2).[4] One mechanism for that is the breaking of the carbon monoxide–nitrogen dioxide ($CO–NO_2$) bond in the nitrocellulose, which is thermally labile and can be broken under storage-temperature conditions. If liberated NO_2 does not react with the nitrate ester (the propellant), it can react with water in air to form acids, which will degrade nitrate esters further. For instance, NO_2 is a strong oxidizer and can react with the nitrocellulose or abstract hydrogen from the nitrocellulose to produce nitrous acid (HONO). The $CO–NO_2$ bond may also be hydrolyzed to form nitric acid (HNO_3). And the degradation of the propellant can be catalyzed by the presence of bases and metals. Finally, the overall chemical reaction is exothermic (it generates heat), and can catalyze degradation further. In other words, the degradation of the nitrate esters in the M28 propellant is accelerated by its own degradation product (NO_2). If the degradation reaction rate becomes high enough, the nitrate ester will self-initiate, and this can lead to ignition, deflagration, or detonation.

Standard practice is to avoid the undesirable consequences of the runaway reaction by adding an NO_2 scavenger, commonly referred to as a stabilizer. The stabilizer does not contribute substantially to the energy delivered by the propellant when used for its intended purpose, so quantities of stabilizer used in propellants are limited. Over time, the stabilizer becomes depleted, and the undesirable reactions can become dominant. Surveillance programs are instituted to ensure that sufficient stabilizer remains in propellants to minimize the risk of autoignition. Such a program consists of accelerated-aging estimations of stabilizer content combined with occasional monitoring of the rocket motor inventory. Conventionally, both evaluations require the extraction of a piece of propellant, followed by chemical analysis of that piece. In 2002, the Army determined that the M28 propellant inside an intact M55 rocket assembly, in its current configuration, could be handled with minimal risk (U.S. Army, 2002). In the 10 years that have elapsed since the 2002 assessment, the propellant has degraded further. If the

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[4] Stephanie E. Leach and Bruce P. Thomas, Naval Air Warfare Center Weapons Division, China Lake, California, “Assessment of Alternative Strategies to Determine Solid Rocket Motor Stability,” meeting poster presented at the 2012 Pittsburgh Conference, March 16, 2012, Orlando, Florida.

propellant has followed the degradation rate projected in 2002, the risk of autoignition should not have increased appreciably. To the committee's knowledge, the propellant has not been assessed since 2002, so it does not know whether the propellant has degraded as projected.

However, cutting the fiberglass SFT and separating the rocket motor from the warhead changes both the system configuration and the storage environment of the rocket motor. For instance, the propellant will have greater exposure to environmental factors, such as heat and humidity, via an air pathway between the rocket motor case and the SFT and up through the nozzle than when it was been sealed in an SFT as a whole rocket. The chemical reactions in the propellant generate heat on an ongoing basis, and the storage box in which the separated rocket motors will be placed will influence heat transfer to and from a given rocket motor and the others boxed with it and heat exchange between ambient air and the propellant. The design of the box, including its ability to dissipate heat generated in the propellant grains and its ability to maintain a dry storage environment, will determine the validity of the previous safety studies vis-à-vis the new configuration of the cut rocket motors.

Other aging-related phenomena that may not correlate directly with the stabilizer content include migration of nitroglycerin into the inhibitor and changes in mechanical properties, such as softening and hardening of the propellant. The M28 propellant contains nitroglycerin, which is used as a plasticizer to tailor the propellant's mechanical properties (to increase its flexibility) and to increase energy content. The nitroglycerin can diffuse and migrate within the bulk propellant, form small accumulations at the propellant surface, be absorbed into the inhibitor layer, or lead to propellant brittleness. Those physical effects can lead to a reduction in propellant stability and an increase in propellant sensitivity, both of which warrant careful consideration in handling aged M28 propellant. Propellant softening is often exhibited as slumping, and propellant hardening can be exhibited as cracking. On initiation, as in some disposal technologies, those phenomena change the surface area being burned and can increase the inner pressure of the motor case. If that pressure exceeds maximum limits for the nozzle or the case, a catastrophic failure will occur and potentially can cause serious damage to personnel and facilities. The phenomena can thus pose a safety risk during rocket motor disposal.

A hazards analysis working group (HAWG) is a useful and important tool for addressing energetics safety (DoD, 2012). A HAWG comprises operators, safety experts, industry experts, vendor representatives, and regulators at BGCAPP could examine in great detail all the possible actions and activities that involve the M55 rocket with specific focus on the energetic material components during demilitarization. A HAWG assessment may reveal safety risks in a process or procedure that are otherwise not readily apparent.

Finding 2-2. The Army's 2002 M55 Rocket Assessment Summary Report for the intact M55 rocket may not be directly applicable to the separated rocket motors. New not-readily-apparent safety risks could emerge during demilitarization operations involving the M55 rocket containing energetic materials.

Finding 2-3. Among the vitally important approved safety practices and procedures that need to be followed in handling energetic materials are the assessment and approval of standard operating procedures and hazard analyses. They will account for potential new safety risks that emerge during the demilitarization process.

Finding 2-4. The design of the storage and shipping box will significantly influence the storage environment of the M28 propellant.

Recommendation 2-2. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should ensure that the storage and shipping containers minimize the exposure of rocket motors to environmental conditions that will accelerate propellant degradation, such as heat and humidity, and allow adequate heat dissipation from the separated rocket motors. For example, desiccant could be added to the storage and shipping containers to reduce humidity.

Recommendation 2-3. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should establish a hazards analysis working group to assess, analyze, and develop risk mitigation practices and procedures with specific attention to energetic materials in the overall demilitarization of the M55 rocket.

ELECTRICAL SAFETY

The hazards of electromagnetic radiation to ordnance (HERO) and electrostatic discharge (ESD) need to be considered as they apply to the separated rocket motors. The rocket-cutting operation will produce a rocket motor with an ignition system configuration that is different from that of an intact M55 rocket. The cutting operation may also damage the igniter leads and shunting as the installed rocket motor ignition system is integrated with the bottom half of the cut fiberglass SFT. Although the rocket-cutting operation is designed not to damage the rocket motor, unintended damage to the igniter leads and the safety shunting may occur when the rocket is cut because the SFT will be clamped at the rear end for this operation, which is where much of the ignition system is. In addition, because the steel rocket motor case will be exposed along the cut, a new electrically conductive path that was not envisioned when the rockets were designed will be created. That may change the system's sensitivity to ESD.

Regarding HERO, the current electromagnetic radiation environment is substantially different from when this ordnance was produced. For example, personal electronic devices and cellular-telephone towers did not exist when the M55 rockets were designed and produced. They can produce local electromagnetic fields that could affect the separated rocket motors and cause electrical safety problems, including possibly ignition.

Finding 2-5. The current hazards to the separated rocket motors posed by electromagnetic radiation and the potential for electrostatic discharge may require verifying the condition of the igniter system after cutting before placement in the storage and shipping box.

Recommendation 2-4. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should address the condition of the ignition system after cutting. If it is warranted by the changed configuration of the separated rocket motors, the design of the storage and shipping box should provide protection from hazards of electromagnetic radiation to ordnance and from electrostatic discharge.

LEAD

As shown in Table 2-1, the M28 propellant contains 2 percent lead stearate by weight. The weight of the propellant in each motor is about 20 lb, so the propellant in each motor contains about 0.4 lb of lead. Lead released from burning propellant will be in the form of respirable particulate matter ($PM_{2.5}$).[5] Releases are likely to be in the form of lead metal and lead oxides. Unpublished data on static-fired rocket motors indicate that a substantial fraction (2-10 percent) of the lead may remain in the motor carcass after firing. Any technology used to dispose of the separated rocket motors would need to ensure minimal redistribution of lead through the environment and protection of employees and the public.

Finding 2-6. Thermal and chemical processes that destroy the propellant will produce a lead waste stream that will present challenges from worker, public health, and environmental exposure perspectives.

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[5] $PM_{2.5}$ is Environmental Protection Agency nomenclature for particulate matter that has an aerodynamic particle size equal to or less than 2.5 μm. That particle size is important because such particles can travel into the alveoli in the lungs.

DoD. 2012. Department of Defense Standard Practice, System Safety, MIL-STD-882E, May 11. Available online at http://www.everyspec.com/MIL-STD/MIL-STD-0800-0899/MIL-STD-882E_41682/. Last accessed July 3, 2012.

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Technologies for Rocket Motor Disposal

RECYCLING OPTIONS

The first choice for any demilitarization or disposal program should be to recover materials. The committee does not believe that this option is practical in the case of the M28 propellant, however, because it is old and degraded. There are few applications for aging rocket motor assets in general, and incorporating nitrate ester rocket motor propellants that are specifically derived from chemical weapons, such as the M28 propellant, into new applications is unlikely.

Attempts to recycle nitrocellulose and nitroglycerin from double-base[1] propellants have not yielded acceptable products. Trace contamination by constituents of a degraded propellant in a recovered material can have a serious adverse effect on the cure times and safe storage life of any propellant made from recovered materials. The nitrocellulose in the M28 propellant is degraded to the point where it is unlikely that any current program of record for manufacturing new rocket propellant would be willing to incorporate it. Furthermore, program-office requalification costs are substantial when alternative sources of fully characterized composition are introduced into a program's inventory. This is an issue especially when a propellant ages and produces chemical species that catalytically degrade the propellant even when they are present only at trace concentrations. Although it might be possible to extract and purify the nitroglycerin for recycling, it would entail much work to determine whether this were worth while. The committee does not believe that it would be a practical or worthwhile exercise. Investigations into conversion of these energetic materials to other products, such as fertilizer, have also met with little success. The fact that the M28 propellant contains lead, which cannot be removed without destroying the propellant matrix by chemical or thermal means, complicates any effort to recycle the propellant into fertilizer and further reduces the practicality of recycling in general.

Finding 3-1. There are no practical, useful, or cost-effective means of recycling energetic materials from the M28 propellant.

Metal components of the separated rocket motor[2] can be recovered for recycling after they have been mutilated to preclude restoration for further use in a rocket motor (DoD, 2011). In addition, metal scrap must be certified as safe for public release and

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[1] The term *double-base* connotes that there are two active constituents in the propellant. In the case of the M28 propellant, they are nitrocellulose and nitroglycerin.

[2] See Appendix A for how the committee defines *separated rocket motor*.

recycling. The Department of Defense (DoD) has instituted a policy for the identification of munitions and munitions scrap that are free of explosive safety hazards (DoD, 2008). The defined process includes specific training, storage, handling, inspection, and certification requirements for all materials potentially presenting an explosive hazard (MPPEH)—that is, any material that has come into contact with an energetic material—before their release from DoD control. The policy applies to any scrap metal recovered from the separated M55 rocket motors.

If the M28 propellant is treated while inside the steel motor case the, remaining metal parts will be contaminated with lead and lead dust. Separation of the propellant, igniter, and other energetic components of the rocket motor from the case, fins, and electronics would simplify the recovery of the scrap metal from these components. However, the recovered metal may still have to be thermally or chemically treated to ensure that energetic residues are destroyed before the materials can be released to a recycler.

Finding 3-2. It is feasible to recycle the metal components of the separated rocket motors.

Finding 3-3. Depending on the destruction technology used, metal components may be contaminated with lead and lead dust.

Recommendation 3-1. The Blue Grass Chemical Agent-Destruction Pilot Plant program staff should inform the recipient of materials for recycling of the potential for the presence of lead or lead dust on recovered materials.

OVERVIEW OF DISPOSAL TECHNOLOGIES

A wide variety of technologies have been proposed for the demilitarization and disposal of conventional solid rocket motors. The technologies can be divided into thermal and chemical. Thermal technologies for separated rocket motor demilitarization and disposal include open detonation, buried detonation, contained detonation, open burn, open static firing, contained combustion, contained static firing, confined combustion, and incineration. Chemical technologies include base hydrolysis, supercritical water oxidation, and the use of humic acid. The chemical technologies typically require pretreatment in which the propellant is broken into a manageable form (e.g., a solution, powder, or slurry). That process increases the handling of energetic materials and the attendant risks. Thermal treatment usually requires less handling, but precautions must be taken to prevent unplanned detonation or propulsive ejection of the rocket motors. Technologies discussed here are summarized in Table 3-1. The committee envisions that the separated rocket motors would be removed from the shipping and firing tubes before disposal of the separated rocket motors, partly because the shipping and firing tubes contain polychlorinated biphenyls; this is discussed in more depth in Chapter 5. Among the criteria that will need to be considered in selecting a disposal technology for use with the separated rocket motors is the TNT equivalence of the roughly 20 lb of M28 propellant in each motor.

THERMAL TECHNOLOGIES

For purposes of the discussion in this report, thermal technologies are organized into two subgroups: open and contained. In open technologies, emissions are not contained or treated before release into the environment. In contained technologies, emissions are contained and treated before release into the environment. A particular subgroup of contained thermal technologies, explosive destruction technologies (EDTs), will also be discussed.

If an open technology were used, the emissions from separated rocket motor disposal would need to be within the allowed limits provided in the Air Pathway Assessment section of the Resource Conservation and Recovery Act (RCRA) Subpart X permit for the facility using the technology. In the case of a contained technology, gases and particulate material would be captured and treated with the unit's pollution abatement equipment. The contained technologies would need to be permitted through RCRA Subpart X and would have to meet release limits agreed on with the Kentucky Department for Environmental Protection.

Open Thermal Technologies

Open Detonation

Open detonation involves placing whole or broken-down rocket motors in a pile with a booster explosive. Detonation of the pile initiates a chemical reaction that converts organic energetic materials to carbon dioxide, nitrogen, and water. Emissions from the process do not undergo further treatment and are released into the local environment. They can include metals in the energetic material (such as lead in the M28 rocket propellant), traces of unreacted energetics, materials in the rocket motor cases released and ejected by the detonation, and entrained soil from the detonation site. Noise issues and weather often limit the conditions under which these detonation events can be conducted.

Open detonation has several advantages. Handling of energetic items is minimized, and this reduces the risk of unexpected initiation and harm to personnel or facilities. Secondary waste streams are limited to unreacted materials, mostly metal components from the detonated solid rocket motors, such as the case and the fins. Data in emissions databases are sufficient to allow an estimation of total emissions from the process (Erickson et al., 2005; EPA, 2009). Efforts are under way to improve the databases (Kim, 2010; Wright et al., 2010).

This technology also has many disadvantages. Emissions are not further treated before release into the environment. In particular, there is a potential for releases of respirable particles from metal components of the energetic formulation, such as the lead in the rocket propellant, or from the soil. Noise issues often cause concerns for facility neighbors and result in regulatory limitations on when the treatment can occur. Propellants like that in the motors of M55 rockets can be difficult to detonate completely, and incomplete detonation occasionally results in distribution of unreacted energetics over a large area. Other unreacted materials, such as rocket motor cases and liners, can also be distributed over a large area. Most permits require regular cleanup of this material. The release of scrap metal from the open detonation process requires prior screening as MPPEH.

Open detonation is a mature technology that is commonly used for munitions demilitarization and emergency ordnance destruction. Throughput from this process will be a function of limits placed on a facility's RCRA Subpart X permit.

Buried Detonation

Buried detonation is a variant of open detonation in which the pile is covered with 4–8 ft of soil to suppress detonation noise. The soil also increases safety by minimizing blast and collateral damage that might be caused by metal fragmentation. This technology has the advantage of minimization of the handling of the items being treated. However, it also has disadvantages. Like emissions from open detonation, emissions from buried detonation are not treated further before release into the environment. Because the soil quenches afterburning reactions, buried detonation releases larger quantities of products of incomplete combustion (such as soot and hydrocarbons) than are produced in open detonation. Little work has been done to quantify this phenomenon, but tests are under way to collect pertinent data (Kim, 2010; Wright et al., 2010). The potential exists for environmental releases of metals and organic substances from both the soil and the waste ordnance.

Buried detonation is a mature technology that is commonly used for munitions demilitarization. Throughput is constrained by permit treatment limits and the time necessary to prepare the site and bury the ordnance.

Open Burning

Open burning of rocket motors involves removal of the propellant grain from the case and ignition of the propellant in an open burning pan. As in open detonation, energetic components are largely converted to nitrogen, carbon dioxide, and water. Some facilities use an additional fuel (such as jet fuel) to initiate and support combustion of propellants that are difficult to ignite. Others conduct open burning of whole rocket motors by cracking the motor case open with a shaped charge that also initiates propellant combustion. Gaseous and particulate emissions from the burning propellant are not treated further and are released into the local atmosphere. The combustion occurs at atmospheric pressure. Residual ash requires evaluation as a potential hazardous waste.

An advantage of open burning is that components of the rocket are removed before treatment and are available for recycling. Data on open-burning emissions are sufficient to permit an estimation of total emissions from the process (Erickson et al., 2005; EPA, 2009), and efforts are under way to improve the quality of the emissions databases (Kim, 2010).

Open burning has several disadvantages in common with open detonation. Emissions do not undergo further treatment before release into the environment. Heavy-metal components of the propellant (such as lead in M28 propellant) are released to the atmosphere as respirable particles. Most propellants are designed to burn efficiently at high pressures. Burning them at ambient atmospheric pressure results in emissions that contain more products of incomplete combustion (such as soot and hydrocarbons) than would be the case if they were burned as designed. Open burning of rocket motors requires the removal of the propellant from the case to prevent propulsive events, and this increases the handling of the items being disposed of. Finally, ash from the process is probably laden with heavy metals from the propellant formulation and must be tested to determine whether it must be handled as a hazardous waste.

This is a mature technology that is commonly used for munitions demilitarization. The Blue Grass Army Depot (BGAD) is operating an open-burning facility under interim permit status. The BGAD facility can treat up to 6,000 lb of energetic material in each treatment event. That would theoretically permit a throughput of up to 300 separated M55 rocket motors per treatment event. The presence of lead in the propellant could lower the throughput because of permit limits on lead releases.

Open Static Firing

Open static firing of rocket motors involves strapping down of the motor and initiating it in its design mode. This is done in the open, so gaseous and particulate emissions are released into the environment without further treatment. The process minimizes handling and simplifies recovery of components of the rocket motor. Catastrophic failure of aged rocket motors is rare, but not unheard of.

The technology has several advantages. As mentioned above, handling is minimal, and this increases personnel safety. The combustion of the propellant occurs at high pressure, which improves combustion efficiency, and there are thermochemical models for predicting emission products. Components of the motor (such as case, fins, and electronics) can be recovered after treatment.

There are, however, some important disadvantages. As in all processes carried out in the open, atmospheric emissions are not treated before release into the environment. With respect to two rocket motor systems that contained a lead burn-rate modifier, as does the M28 propellant in the rocket motors separated from M55 rockets, it was one committee member’s direct experience that a nontrivial fraction of the lead remained in the case after treatment. The committee believes that it would be prudent to expect that the motor case will require assessment as hazardous waste because of lead contamination in addition to being managed as MPPEH. There is a potential for propellant cracking, slumping, shrinking, or changing in density as the propellant ages. Those phenomena can change the propellant surface area during burning. In extreme cases, they can result in overpressurization and catastrophic failure of the rocket motor. Such a failure can damage facilities and may initiate a re-evaluation of procedures.

This is a mature technology that is commonly used for munitions demilitarization. Throughput will be limited by environmental permits, the number of motors strapped to a test stand, and the time necessary to wire the initiation circuitry.

Contained Thermal Technologies

Contained Detonation

Contained detonation involves the detonation of the rocket motor or the rocket motor propellant in a sealed chamber. Contained detonation technologies often use a donor explosive charge to detonate the propellant. Afterburning reactions are often quenched as a result of efforts to protect the integrity of the chamber. After detonation, gases in the chamber are passed through a pollution-abatement system to remove contaminants before venting to the local atmosphere. To preserve the detonation chamber, limits are placed on the quantity of energetic material that can be treated in a single detonation, and this restricts process throughput. Designs for contained detonation units are commercially available.

This technology has some advantages, such as minimization of the handling of the items being disposed of. Furthermore, emissions are treated before release into the environment. It also has several disadvantages. Over time, shrapnel can cause damage to the facility and result in repair costs and possibly an interruption of processing. That and other stressors also limit the lifetime of the detonation chamber. Large scrap residues need to be removed after each treatment event to minimize the production of shrapnel. The time needed for such clearance limits throughput of the technology. Toxic metal, semivolatile, and nonvolatile emissions from the ordnance will contaminate the interior of the detonation chamber. In the case of the separated rocket motors, such contaminants would include the lead compounds from the M28 propellant. The contaminants would pose a safety risk to personnel operating in the chamber. In addition, it is difficult to ensure that a detonation chamber will remain leakproof over a lifetime of contained detonations; avoidance of environmental contamination requires regular checks for leaks.

Contained Combustion

Contained combustion involves the burning of energetics in burn pans in a sealed combustion chamber. Gaseous and particulate emissions from the combustion process are stored in a holding tank for later processing before release into the environment. Handling is minimized, but gas storage capacity can be a limiting factor. The time required for postcombustion cleanup of the combustion chamber may decrease processing throughput.

The minimization of handling and the treatment of emissions before environmental release are advantages of this technology. However, as with contained detonation, emissions of toxic metals, semivolatile compounds, and nonvolatile compounds from the ordnance will contaminate the interior of the chamber and pose a risk to personnel safety, and lead compounds would be a contaminant from the combustion of M28 propellant. In addition, residues will require assessment for treatment as hazardous waste, and metal scrap must be managed as MPPEH. Throughput will be limited by workplace cleanliness standards and the time needed to treat collected combustion gases.

Contained Static Firing

Contained static firing involves the burning of an intact rocket motor or propellant in a combustion chamber. Gaseous and particulate emissions from the combustion process are stored in a holding tank for later processing before release into the environment. Handling is minimized, but gas storage capacity and the potential for damage from a catastrophic failure limit throughput.

Minimization of handling and treatment of emissions before environmental release are advantages of this technology. However, the motor residues would need to be removed after each treatment event, and this will limit process throughput. As with contained detonation and contained combustion, emissions of toxic metals, semivolatile compounds, and nonvolatile compounds from the ordnance will contaminate the interior of the chamber and pose a risk to personnel safety. As above, one of the contaminants in disposal of the M28 propellant will be lead compounds. Motor residues will require assessment for treatment as hazardous waste, at least in part because of the presence of lead compounds, and as MPPEH. There is a potential for propellant cracking, slumping, or shrinking and changes in density as the propellant ages. Those phenomena can change the propellant surface area during burning. In extreme cases, that can result in overpressurization and catastrophic failure of the rocket motor. Such a failure can damage facilities and may initiate a re-evaluation of procedures. This technology is commercially available.

Confined Combustion

Confined combustion burns a rocket motor in a combustion chamber and, in contrast with contained combustion, passes product gases through a pollution-abatement system to remove atmospheric pollutants before release into the environment. Few commercial pollution-abatement systems can handle the large changes in temperature, pressure, and flow rate that occur over the short period of rocket motor combustion. Throughput is limited by requirements for setup and chamber cleanup between motor firings.

As with contained combustion, advantages of this technology include the minimization of handling and the treatment of emissions before environmental release. The limited availability of commercial pollution-abatement systems that have the capacity to handle the operational environment of this technology is a potential disadvantage. The motor case needs to be removed from the chamber after each treatment event to minimize damage to the chamber from flying debris and thus prevent shutdown of the unit, which would limit throughput. Emissions of toxic inorganic, semivolatile, and nonvolatile chemicals from the ordnance will contaminate the interior of the chamber and pose a risk to personnel safety. The motor case will require assessment for treatment as hazardous waste at least in part because of the presence of lead compounds and will also need to be managed as MPPEH.

This technology has undergone subscale and pilot-scale demonstration. Further development is needed to make it directly applicable to the disposal of rocket motors separated from M55 rockets.

Other Thermal Disposal Technologies

Various other thermal technologies have been applied to the demilitarization and disposal of solid propellant rocket motors. They include incineration by rotary kiln, plasma arc, and fluidized bed technologies. As a group, the techniques involve the placement of the propellant or rocket motor into an externally heated chamber and then thermally induced detonation, deflagration, or combustion of the energetic material. Chamber walls are designed to contain the detonation products and shrapnel. Atmospheric emissions are typically passed through commercial pollution abatement systems before release into the environment. Thermal technologies are commercially available from various sources.

Four explosive destruction technologies (EDTs) have been and are being evaluated for disposal of the rocket motors separated from the M55 rockets stored at BGAD and for other uses in chemical demilitarization and disposal processes.[3] These EDTs are a subset of the conventional demilitarization and disposal technologies described in this chapter. The EDTs can be used to implement contained burning, detonation, or perhaps static-firing technologies. They are called out separately because they are already familiar to the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) project staff, the public around BGAD, and some state regulators. The four EDTs are as follows:

- Detonation of Ammunition in a Vacuum Integrated Chamber (DAVINCH), such as the DAVINCH DV65 manufactured by Kobe Steel, Ltd. This process would involve the detonation of a separated rocket motor with a donor explosive in an evacuated chamber that will withstand the detonation. Emissions are treated with a pollution-abatement system. A larger version of the DV65, the proposed DV120, would have a throughput of 36 separated rocket motors in a 10-hour day (NRC, 2009).
- Sandia National Laboratory's Explosive Destruction System (the EDS-1 and EDS-2). This contained detonation process would involve the detonation of a separated rocket motor with a donor explosive in a chamber designed to withstand the blast and contain the shrapnel and gases and then treatment of the emissions. Currently available EDS units are designed to contain the explosive force from not more than 4.8 lb TNT-equivalent net explosive weight and thus do not have the capacity to treat intact M55 separated rocket motors (NRC, 2009). In addition, the EDS is designed to crack open munition casings to access chemical agent fills and then chemically neutralize the agent. It is not designed primarily for the disposal of energetic materials.
- The Static Detonation Chamber, such as the SDC 2000 from Dynasafe AB. Energetic materials are dropped into a preheated blast chamber, where they burn, deflagrate, or detonate. Shrapnel is contained in the blast chamber, and gaseous emissions are passed to a holding tank for treatment. Dynasafe has proposed an enlarged version of the SDC 2000 to treat about 100 separated rocket motors in a 10-hour day (NRC 2009). An SDC has been used at the

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[3] See NRC, 2006 and NRC, 2009 for more detailed information.

Anniston Chemical Agent Disposal Facility to dispose of overpacked and problem munitions that could not be readily processed through the facility.

- Detonation chambers, such as the Transportable Detonation Chamber and the Contained Detonation Chamber, manufactured by CH2M HILL. As constructed, these are contained detonation chambers. CH2M HILL has proposed using a modified version of the D-100 chamber currently installed at BGAD as a contained static-firing chamber in which separated rocket motors would be fired in their design mode into a containment vessel before treatment of the exhaust products. It has been estimated that this approach would permit the treatment of 180 separated rocket motors in a 10-hour day (NRC 2009). A Transportable Detonation Chamber was used at Schofield Barracks, Hawaii, to dispose of recovered chemical weapons materiel.

CHEMICAL TECHNOLOGIES

Base Hydrolysis

In base hydrolysis, energetic waste is added to water at a mild temperature (90–150°C) and high pressure (200 psig) with a strong base (pH > 12). Organic components of the energetic waste are converted to water-soluble nonenergetic materials. The feed rate needs to be controlled to prevent a violent exothermic reaction, that is, deflagration or detonation of the propellant. To control the feed rate and ensure efficient and thorough reaction, it is usually necessary to add propellant to the caustic solution as a slurry. A key advantage of this technology is that energetic waste is converted to water-soluble nonenergetic products, but the resulting solution is still hazardous and must be treated further.

Supercritical Water Oxidation

Supercritical water oxidation treatment (SCWO) involves addition of a powdered, liquid, or aqueous slurry of energetic waste to a solution of water and an oxidizer at high temperature (over 374°C) and high pressure (over 3,000 psig). The organic waste is broken down to water-soluble, nonenergetic materials. Inorganic waste components, such as lead, are oxidized to insoluble salts that can be filtered out of the waste stream. SCWO is already being installed at BGCAPP to treat the products of the chemical neutralization of chemical agent and energetic materials. Use of this technique on the M28 propellant will require some preprocessing to get the energetic into an amenable form.

An advantage of this technology is that all organic chemicals are fully decomposed and inorganic materials can be filtered out of the process stream. However, the feedstock is usually in the form of a liquid or slurry, so it would be necessary to remove propellant from motor and pretreat it to get it into an appropriate form; this increases the amount of handling required with the concomitant risks. This is a commercial technology that has been used on a pilot scale to treat waste energetics.

Humic Acid Treatment

Humic acid treatment involves heating the propellant in a vat that contains a mixture of caustic and humic acids. Phosphate is usually added to immobilize heavy metals. The resulting products can usually be used as fertilizer, but application of the technique to M28 rocket propellant disposal would require experimentation to verify that lead in the propellant remains immobile and that other toxins are thoroughly destroyed.

The production of fertilizer could be an advantage of this technology. However, the presence of lead and other toxins in the propellant could hinder the manufacture of fertilizer. Furthermore the technique has been applied to only a few propellant formulations. Where it has been successful, substantial work has been required to achieve that success. The committee is not aware that humic acid has been used to treat a propellant similar to the M28 propellant in the M55 rockets, and there is a lack of data with which to assess whether it would be successful in treating this propellant. The technology has been demonstrated on a pilot scale.

SUMMARY

Table 3-1 shows a comparison of advantages and disadvantages of each technology described here, and Table 3-2 presents the committee's judgment of technology status and identifies technology developers or users. Regardless of where the propellant is demilitarized, the selected facility must deal with handling, treatment, and transportation of the propellant and with any political and treaty issues involved with items derived from chemical weapons. Most of the facilities listed in Table 3-2 have not been used to demilitarize rocket motors derived from chemical weapons.

Table 3-2 presents estimated process throughputs for each technology on which such information was available. It has been estimated (see Chapter 4) that a separated rocket motor processing throughput rate of 167 motors per day will be needed to keep pace with M55 rocket processing at BGCAPP.

Open thermal technologies result in atmospheric releases of respirable lead dust from the M28 propellant. That may place an additional constraint on the throughput of these technologies. For instance, although a facility may be able to process sufficient net explosive weight to dispose of 167 or more separated rocket motors per day, permit restrictions on lead releases could potentially result in much lower throughput. Contained thermal technologies, such as the EDTs, will prevent the release of lead into the environment. The estimated throughput for any of the EDTs has yet to be validated.

A detailed consideration of public sentiment about disposal technologies is beyond the scope of this committee's work, but the public around BGAD, although now closely involved in discussions about key project decisions, has historically used political and permitting processes to attempt to achieve the outcomes that they desired. Thus, the committee recognizes that public sentiment, albeit a nontechnical issue, could be an important factor in how readily any disposal technology can be implemented and believes that it should be mentioned in this report.

The public around BGAD has been strongly opposed to the use of incineration to dispose of chemical munitions and the resulting waste streams, such as the separated rocket motors. The public around BGAD is strongly committed to disposing of as much material as possible at BGCAPP by chemical neutralization followed by SCWO. However, willingness to consider the use of alternative technologies, such as the EDTs, in limited applications where safety and other compelling concerns point to them as the best options has been developing. That subject is covered in more depth in Appendix B. A key concern of the public around BGAD has been the release of toxic materials into the environment. Complete containment of emissions from disposal processes is very important to the public. That might indicate that, overall, a contained technology might be more easily implemented than an open technology.

Finding 3-4. Thermal treatment demilitarization and disposal operations performed in a chamber require the least handling and permit treatment of product emissions. Chemical technologies either are not mature or are not readily implementable for the disposal of the separated rocket motors.

Finding 3-5. The presence of lead in the M28 propellant may significantly constrain the throughput rate for disposing of separated rocket motors with open thermal technologies because of permit limits on the environmental release of lead.

Finding 3-6. The public around the Blue Grass Army Depot has historically been concerned about the release of toxic materials into the environment. Public concerns have been important in the disposal of chemical munitions and related wastes. They could also affect how readily a technology for the disposal of separated rocket motors could be implemented.

Finding 3-7. A contained thermal technology is the best option for disposing of the rocket motors separated from the M55 rockets stored at the Blue Grass Army Depot.

TABLE 3-1 Technology Comparison

Technology	Description	Advantages	Disadvantages
Open detonation	Ordnance is placed on a pile, surrounded with donor explosive, and detonated.	Handling is minimized. Secondary waste streams are limited to unreacted materials, mostly metal case components. Sufficient data are present in emissions databases to permit estimation of process emissions. Efforts to improve the databases are under way.	Atmospheric emissions are not treated further. Potential releases of respirable heavy-metal particles from the rocket motor or soil. Unreacted materials can be distributed over a large area.
Buried detonation	Propellants and donor are buried under 4–8 ft of soil and detonated.	Handling is minimized. Noise is less than for open detonation.	Atmospheric emissions are not treated further. The presence of large quantities of soil in the plume suppresses afterburning and increases concentrations of products of incomplete combustion. Little work has been done to quantify this phenomenon, but tests to collect pertinent data are under way. There is a potential for environmental releases of metals and organic chemicals from soil and ordnance.
Open burning	Loose propellant is placed into a pan and initiated. Some facilities use an additional fuel (e.g. JP-8) to initiate and support combustion. Some facilities initiate the process by cracking open a rocket motor case with a shaped charge.	Components of the missile are removed before treatment. Data in emissions databases permit estimation of process emissions. Efforts to improve the databases are under way.	Emissions are not processed further. Most propellants are designed to burn efficiently at high pressure. Burning at atmospheric pressure results in incomplete combustion. There would be atmospheric releases of respirable heavy metals (e.g., lead) from the propellant. Rocket motors require prior removal of the propellant from the case to prevent the possibility

TABLE 3-1 Continued

Technology	Description	Advantages	Disadvantages
			of propulsive events; this increases ordnance handling. Ash from the process must be treated as MPPEH[a] and is probably laden with heavy metals.
Open static firing	The rocket motor is secured, then initiated in its design mode.	Handling is minimized. Combustion occurs at high pressure, and this improves efficiency. There are thermochemical models for predicting emission products. Components of the rocket motor (such as case, fins, and electronics) can be recovered after treatment.	Atmospheric emissions are not treated further. A nontrivial fraction of lead in the propellant remains in the carcass after treatment in the form of lead metal and lead oxide dust. The carcass will require assessment as hazardous waste and MPPEH.[a] Aged propellant can crack, slump, shrink, or change density. In extreme cases, that can result in overpressurization of the motor bottle after ignition, which can lead to catastrophic failure of the rocket motor. Such a failure can damage facilities and may initiate a re-evaluation of procedures.
Contained detonation	An ordnance item or energetic component is placed into a sealed detonation chamber. A donor charge is often required. The detonation reaction is initiated. Afterburning reactions are often quenched as a result of efforts to protect the integrity of the chamber. After detonation, product gases and particles are passed through pollution control instrumentation to remove undesirable contaminants.	Handling is minimized. Emissions are treated before release into the environment.	Over time, shrapnel can damage the facility and limit facility lifetime. Large residues need to be removed after each treatment event to minimize shrapnel. Emissions of toxic metal, semivolatile chemicals, or nonvolatile chemicals from the ordnance will contaminate the interior of the detonation chamber. Regular leak checks are needed to prevent environmental contamination as the detonation chamber ages.

TABLE 3-1 Continued

Technology	Description	Advantages	Disadvantages
Contained combustion	Propellant is placed into a pan in a combustion chamber and initiated. Product gases are collected in a holding tank and then processed through a pollution abatement system.	Handling is minimized. Emissions are treated before environmental release.	Large residues need to be removed after each treatment event to minimize damage to the chamber from flying debris. Emissions of toxic metal, semivolatile chemicals, and nonvolatile chemicals from the combustion will contaminate the interior of the burn chamber. The carcass will require assessment as hazardous waste and MPPEH.[a]
Contained static firing	The rocket motor is secured and fired into a containment vessel in its design mode. After combustion, atmospheric contaminants are processed through a pollution abatement system.	Handling is minimized. Combustion occurs at high pressure, and this improves efficiency. Emissions are treated before environmental release.	A nontrivial fraction of lead in the propellant remains in the carcass after treatment in the form of lead metal and lead oxide dust. Emissions of toxic metal, semivolatile chemicals, and nonvolatile chemicals from the combustion will contaminate the interior of the burn chamber. The carcass will require assessment as hazardous waste and MPPEH.[a] Aged propellant can crack, slump, shrink, or change density. In extreme cases, that can result in overpressurization of the motor bottle after ignition and lead to catastrophic failure of the rocket motor. Such a failure can damage facilities and may initiate a re-evaluation of procedures.
Confined combustion	A rocket motor is placed into a combustion chamber and initiated. Product gases are not contained but are passed immediately through pollution abatement	Handling is minimized. Emissions are treated before environmental release.	Few commercial atmospheric filtration devices are capable of real-time handling of the changes in temperature, pressure, and flow rate that occur during a motor firing. Large residues need to be removed after each

TABLE 3-1 Continued

Technology	Description	Advantages	Disadvantages
	equipment before release into the environment. Work at China Lake involved burning of full-scale rocket motors with the nozzle removed.		treatment event to minimize damage to the chamber from flying debris. Emissions of toxic metal, semivolatile chemicals, and nonvolatile chemicals from the ordnance combustion will contaminate the interior of the burn chamber. The carcass will require assessment for treatment as hazardous waste and MPPEH.[a]
Rotary kiln	This is an enclosed incinerator in which waste is slowly moved from one end to the other. Waste material detonates or combusts. Emissions are treated.	High feed rates have been demonstrated. Emissions are treated.	Deflagration or detonation of energetic materials can damage facilities and interrupt operations. Few atmospheric filtration devices are capable of handling the extreme changes in pressure and flow rate that occur during a large detonation event; this will limit the treatment rate. Careful control of feedstock and combustion conditions is needed to minimize production of toxins like dioxins.
Fluidized bed	Energetic waste is injected into a turbulent bed of hot sand.	Emissions can be treated.	The technique is limited to liquids, slurries, and powders that have low inorganic content. Substantial handling is needed to remove solid propellants and convert them to a form amenable to treatment.
Static Detonation Chamber[b]	Ordnance is dropped into a heated chamber, where it detonates, deflagrates, or combusts. Product gases are scrubbed with a pollution abatement system.	Handling is minimized. Emissions are scrubbed.	The furnace will need to be turned off regularly to empty the chamber of collected incombustible residues. Residues from rocket motors separated from M55 rockets will probably be contaminated with

TABLE 3-1 Continued

Technology	Description	Advantages	Disadvantages
			lead and require lead abatement to handle. Facility lifetime is limited by damage to the detonation chamber from shrapnel.
Base hydrolysis	Energetic wastes are added to water and heated to mild temperatures (90–150°C) usually at high pressure (200 psig) with a strong base (pH > 12); this chemically degrades the energetic materials.	Energetic waste is converted to water-soluble nonenergetic products.	The resulting solution is still hazardous and must be treated further. Careful control of feed rate is needed to prevent the deflagration or detonation of propellant.
Supercritical water oxidation	Organic waste, water, and an oxidizer (such as hydrogen peroxide) are subjected to high temperature (>374°C) and pressure (>3,000 psig); this chemically degrades the organic waste.	Organic chemicals are decomposed.	Feedstock is usually in the form of a liquid or slurry. It is necessary to remove propellant from the motor and pretreat it to get it into an appropriate form.
Humic acid treatment	Energetics are heated in a vat that contains a mixture of caustic and humic acids. Phosphate is usually added to immobilize heavy metals.	Product is fertilizer.	Used to date only on a few propellants. The record of success is mixed. The method might require much work for application to M28 propellant. There is a lack of data with which to assess the likelihood that the technology will work on M28 propellant.

[a] MPPEH, materials potentially presenting an explosive hazard.
[b] See discussion in section “Other Thermal Disposal Technologies”.

TABLE 3-2 Technology Status and Applicability

Technology	Technology status	Technology developer or representative user	Estimated M55 rocket motor throughput[a]
Open detonation	Mature	Naval Air Weapons Station, China Lake (user)	N/A
		Hill Air Force Base (user)	N/A
Buried detonation	Mature	Tooele Army Depot (user)	N/A
		Defense Ammunition Center (user)	N/A
		Anniston Army Depot (user)	N/A
Open burning	Mature	Naval Surface Warfare Center, Indian Head (user)	N/A
		BGAD (user)	300 per event
Open static firing	Mature	Tooele Army Depot (user)	N/A
		Anniston Army Depot (user)	N/A
		McAlester Army Ammunition Plant (user)	
Contained detonation	Commercially available	Naval Surface Warfare Center, Crane (developer and user)	N/A
		Tooele Chemical Agent Destruction Facility (user, DAVINCH DV65)	N/A
		CH2M HILL (developer, D-100 Detonation Chamber)	N/A
		Kobe Steel (developer, DAVINCH)	36 per day for the Kobe Steel DAVINCH DV120 (NRC, 2009)
Contained combustion	Commercially available	Naval Surface Warfare Center, Crane (developer and user)	N/A
		Naval Surface Warfare Center, Indian Head (developer and user)	N/A
		CH2M Hill (developer)	N/A
Contained static firing	Commercially available	Naval Air Warfare Center, China Lake, in partnership with Lockheed-Martin (developer)	N/A
		El Dorado Engineering	N/A

TABLE 3-2 Continued

Technology	Technology status	Technology developer or representative user	Estimated M55 rocket motor throughput[a]
		(developer)	
		CH2M Hill (developer, D-100 Detonation Chamber)	180 per day for static firing in the CH2M HILL D-100 Detonation Chamber (NRC, 2009)
Confined combustion	Sub-pilot and pilot scale	Naval Air Warfare Center, China Lake, in partnership with Lockheed-Martin and Bechtel (developer)	N/A
Rotary kiln	Commercially available for small munitions	Tooele Army Depot (user)	N/A
Fluidized bed	Pilot scale	Defense Ammunition Center (user)	N/A
Static Detonation Chamber	Commercially available	Anniston Chemical Agent Disposal Facility (user) Dynasafe AB (developer)	100 per day, upgraded SDC-2000 (NRC, 2009)
Base hydrolysis	Commercial process	Defense Ammunition Center (user)	N/A
Supercritical water oxidation	Commercial process	Defense Ammunition Center (user)	N/A
Humic acid treatment	Pilot-scale demonstration	Defense Ammunition Center (user)	N/A

[a] Estimate based on a 10-hour workday.

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4
Storage of Separated Rocket Motors

THE NEED FOR STORAGE SPACE FOR SEPARATED ROCKET MOTORS

For a variety of reasons (e.g., permit restrictions and throughput capability), the rate at which any given technology disposes of the separated rocket motors[1] will probably be lower than the rate of rocket-cutting operations in the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP). Disposal of the separated rocket motors therefore has the potential to be a limiting step in overall M55 rocket disposal. Rocket motor storage and transportation to an eventual disposal facility (either on-site or off-site) will mitigate the impact of the disparate processing rates, but separated rocket motor storage is a potential and serious bottleneck that could affect the planned rate of M55 rocket-cutting operations at BGCAPP. BGCAPP will have temporary storage for the separated rocket motors. However, once the storage area reaches capacity, if the separated rocket motors cannot be transported to an outside storage or disposal site at least as quickly as they are being produced, they will accumulate at BGCAPP, and the planned rocket-cutting and warhead-processing operations would need to be slowed or halted. The centrality of storage of separated rocket motors is shown in Figure 4-1.

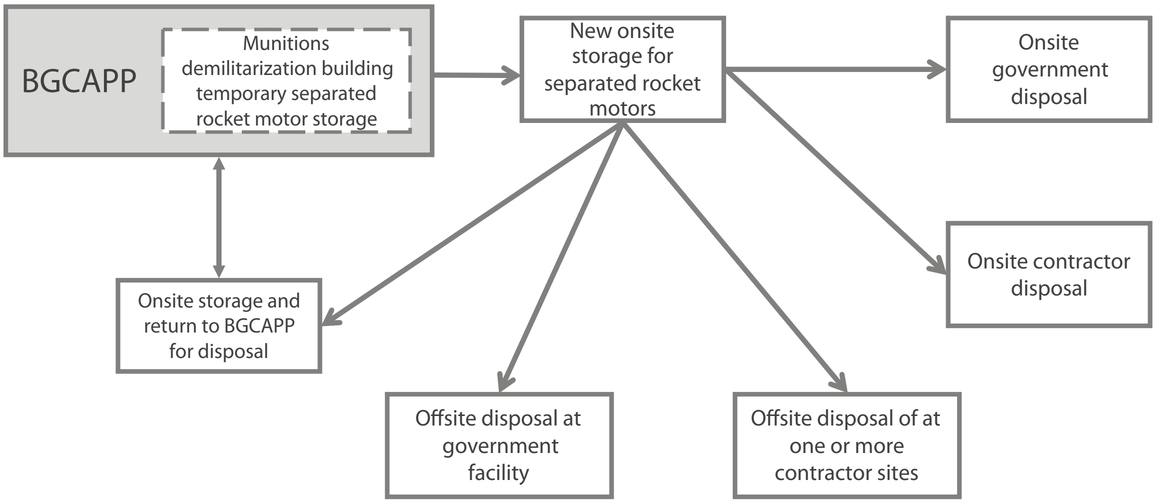

FIGURE 4-1 Diagram showing the importance of storage for the disposal of separated rocket motors.

Finding 4-1. The provision of adequate storage space for the separated rocket motors is important for the overall rate of operations for M55 rocket disposal at the Blue Grass

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[1] See Appendix A for how the committee defines *separated rocket motor*.

Chemical Agent-Destruction Pilot Plant. Rocket-cutting and warhead-processing operations would need to be slowed or halted if the combination of storage capacity and separated rocket motor disposal could not meet the rate at which separated rocket motors are produced.

REQUIREMENTS FOR STORAGE OF SEPARATED ROCKET MOTORS

It is estimated that the peak processing rate of M55 rockets at BGCAPP will be 20 GB-filled rockets per hour or 24 VX-filled rockets per hour, producing 20 or 24 separated rocket motors, respectively, per hour. Overall, BGCAPP estimates that about 3,350 separated rocket motors would be ready for disposal per month. The munitions demilitarization building is designed for a storage capacity of 1.25 operating days.[2] There is currently no additional designated storage space for separated rocket motors at the Blue Grass Army Depot (BGAD) apart from the planned storage area at BGCAPP.

The limited storage capacity subjects the M55 processing operations to delays if unexpected events occur, such as a shutdown of a rocket motor disposal facility in the event of a safety incident or transportation delay. It is important to have storage capacity sufficient to permit continuing rocket processing at BGCAPP if upsets in the schedule of disposal of separated rocket motors occur.

It is also necessary to meet Environmental Protection Agency (EPA) and Kentucky requirements regarding hazardous waste storage. The separated rocket motors are explosive hazardous waste, and Resource Conservation and Recovery Act (RCRA) requirements regarding storage of explosive hazardous waste must be met. Once a rocket motor is separated from the warhead, the motor must be stored in a designated hazardous waste storage site. The planned BGCAPP storage area can serve as a hazardous waste storage site, but accumulating hazardous waste must comply with 40 CFR 262.34, which limits the time that explosive hazardous waste can be stored before being disposed of. Noncompliance with EPA and Kentucky hazardous waste regulations can result in enforcement actions and fines.

CREATING ADDITIONAL STORAGE SPACE AT THE BLUE GRASS ARMY DEPOT

The creation of expanded new safe storage space on site at BGAD outside the physical boundaries of the BGCAPP facility would provide greater assurance that M55 rocket processing could continue without interruption caused by limits on safe storage-space capacity. The committee believes that it is much more likely that substantial additional safe storage space can be created on site at BGAD than at BGCAPP. Furthermore, safe intra-installation transportation will facilitate movement of separated rocket motors to any newly created safe storage space at BGAD.

The requirements for additional safe storage space on site at BGAD depend on many factors. For example, the designated hazard classification of the separated rocket

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[2] Ron Hawley, Plant General Manager, Bechtel Parsons Blue Grass Team, “Rocket Processing,” presentation to the committee, March 20, 2012.

motors will define the quantity that may be stored at a given location, the distance required between the storage area and other activities, and additional security and siting issues (U.S. Army, 2011). Storage of rocket motors at BGAD would need to be in magazines site-approved for storage of Hazard Class 1 materials. The magazines would also need to meet both RCRA hazardous waste regulations and explosive safety requirements. The site-approved magazines would need to be designated as long-term (180-day) RCRA explosive hazardous waste sites and be managed as such as provided in Section 3500 of RCRA and in 40 CFR 270. (Hazard classification is discussed in more depth in Chapter 2.)

The committee has been informed that preliminary discussions between BGCAPP and BGAD staff indicate that magazine storage space at BGAD is limited and may already be filled to capacity. Nonetheless, because BGAD conducts demilitarization of waste military munitions as part of its mission, the installation may already have RCRA-permitted magazines designated for storage of waste military munitions or other explosive hazardous waste munition components that could be used for storage of separated rocket motors.

Finding 4-2. The planned rocket destruction throughput at the Blue Grass Chemical Agent-Destruction Pilot Plant may be at risk because of insufficient capacity for storage of separated rocket motors.

Recommendation 4-1. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should secure additional space for storage of separated rocket motors. It is essential that discussion with Blue Grass Army Depot staff concerning the option for securing such additional space at the depot be given high priority.

If the separated rocket motors qualify as waste military munitions, an alternative option would be to designate BGAD magazines as conditionally exempt magazines[3] for storage of waste military munitions. That would allow long-term storage as long as quarterly monitoring of the condition of the stored materials is documented and records of it are provided to the state. Kentucky has not adopted the Munitions Rule (see 40 CFR 266.202) and has not developed any state-specific military munitions rules. Military munitions are regulated by the Division of Waste Management of the Kentucky Department for Environmental Protection. Regulations for the state's RCRA hazardous waste management, including military munitions, are provided in Title 401, Natural Resources and Environmental Protection Cabinet, Department for Environmental Protection, Chapters 30–36 and 38 of the Kentucky Administrative Rules (KAR), with definitions in Chapter 224 of the Kentucky Revised Statutes (KRS). The process would thus require coordination with the Kentucky Department for Environmental Protection.

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[3] 40 CFR 266.205(a) gives the storage requirements (and exemptions) for munitions that are exempted from being considered RCRA hazardous waste, as set forth in 40 CFR 266.203 (3)(1). When following or invoking these definitions and requirements the military calls the storage areas conditionally-exempt magazines.

Finding 4-3. If the separated rocket motors qualify as waste military munitions, magazines could potentially be designated as conditionally exempt to allow long-term storage of separated rocket motors.

RETURNING SEPARATED ROCKET MOTORS TO THE M55 ROCKET STORAGE IGLOOS

One possibility for additional safe storage of separated rocket motors would appear to be returning them to the existing M55 rocket igloos as the igloos are vacated. However, lethal and incapacitating chemical munitions and agents (that is, chemical surety material) are generally stored separately from conventional ammunition and explosives. The igloos in which the M55 rockets were originally stored could not readily be used for storage of the separated rocket motors unless appropriate explosive safety site approvals were obtained. A new application for site approval for storing rocket motors in the original rocket storage igloos would need to be submitted and approved by the Department of Defense Explosive Safety Board. Approval from the Kentucky Department for Environmental Protection would also likely be necessary. The igloos would need to be free of contamination with chemical agents before being reused for storing separated rocket motors. Because of the logistics of the movement of M55 rockets out of the igloos, the turnaround time for producing separated rocket motors that need storage, and the time necessary for obtaining site approvals, returning separated rocket motors to igloos for storage would require much planning and coordination.

Finding 4-4. Reusing emptied M55 rocket storage igloos for storage of separated rocket motors is a possible solution to the problem of inadequate storage space. Pursuing this option would entail much coordination and planning and would take time.

Recommendation 4-2. If a decision is made to pursue this option, Blue Grass Chemical Agent-Destruction Pilot Plant program staff should prepare a plan to convert the M55 rocket storage igloos to hazardous waste storage sites that are also site-approved for the storage of explosives. The plan should include management of the transition without the need to submit separate approval requests one igloo at a time.

PROPELLANT DEGRADATION, STABILIZER DEPLETION, AND STORAGE RISK

It is well understood that double-base rocket propellants, such as the M28 propellant in the M55 rockets, are subject to chemical degradation that decreases their stability in storage and increases storage risk.[4] Propellant degradation is mitigated by a chemical additive called a stabilizer, such as 2-nitrodiphenylamine, that is depleted as it traps the reactive gases that result from propellant degradation. Stabilizer depletion in

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[4] *Storage risk* is defined in Appendix A.

turn can lead to a risk of autoignition of the propellant. Thus, storage risk increases with storage time. Although stabilizer depletion is known to occur in the case of M28 propellant, previous studies have estimated that the frequency of autoignition of propellant in intact M55 rockets and the overall storage risk are very low (U.S. Army, 2002).

The storage risk may be greater in the case of separated rocket motors than intact M55 rockets. The shipping and firing tube that contains the intact M55 rocket isolates the rocket motor from environmental conditions. During processing at BGCAPP, the shipping and firing tube is cut, and this exposes the separated rocket motor to environmental factors, such as humidity and heat, more than when it is part of an assembled M55 rocket. Humidity can accelerate chemical reactions with the nitrogen oxide gases formed from the degrading nitrate ester. The nitrogen oxide gases accelerate nitrocellulose decomposition and stabilizer depletion; this leads to a self-accelerating cycle. Heat also increases the stabilizer depletion rate in the M28 propellant by increasing the rate of nitrocellulose degradation. The storage of intact M55 rockets in their pallets and in overpacked configurations and their ability to dissipate excess heat from the propellant were studied in 2002. The study found no immediate risk of propellant autoignition in these configurations (U.S. Army, 2002). However, when the rocket motors are separated from the M55 rockets and placed in new packaging, they are in a new configuration, and prior safe-storage assessments may not be directly applicable. Thus, separated rocket motors may have a shorter safe-storage life than assembled M55 rockets.

Finding 4-5. Storage risk may increase more quickly in the case of separated rocket motors than assembled M55 rockets because of the increased environmental exposure of the separated motors. The effects of this environmental exposure on the separated rocket motors have not been characterized.

Recommendation 4-3. The Blue Grass Chemical Agent-Destruction Pilot Plant program staff should dispose of separated rocket motors as soon as possible, using a “first in, first out” protocol to minimize storage time and reduce risk.

REFERENCES

U.S. Army. 2002. M55 Rocket Assessment Summary Report, July. Aberdeen Proving Ground, Md.: U.S. Army Program Manager for Chemical Demilitarization.

U.S. Army. 2011. Ammunition and Explosives Safety Standards, Department of the Army Pamphlet 385–64, May 24. Available online at http://armypubs.army.mil/epubs/pdf/p385_64.pdf. Last accessed May 17, 2012.

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Options for Disposal of Separated Rocket Motors

In view of the various considerations and disposal technologies and their advantages and disadvantages, discussed in previous chapters, a variety of possible options exist for the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) and the Blue Grass Army Depot (BGAD) to dispose of rocket motors separated from the M55 rockets stored at BGAD. These options, which fall into two main groups, were evaluated by the committee:

- On-site disposal options,
  - Open burning of the propellant grain at the BGAD permitted explosive hazardous waste treatment facility,
  - Using the D-100 chamber currently at BGAD,
  - Disposal using alternative technologies (technologies not currently resident at BGAD) that can be added to BGAD capabilities,
  - Disposal at the BGCAPP facility after completion of all chemical agent destruction operations, and
- Off-site disposal options.

The committee envisions that the separated rocket motors would be removed from the shipping and firing tubes (SFTs) before the motors are disposed of, in part because the SFTs contain polychlorinated biphenyls (PCBs). The issue of PCBs is discussed in more detail below.

ON-SITE[1] DISPOSAL OPTIONS

Open Burning of Propellant Grain at the BGAD Permitted Facility

If the SFT and the rocket motor case can be cut such that the propellant grain could be readily removed from the rocket motor case, open burning of the propellant is an

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[1] In this report, the committee is using *on-site* to indicate disposal not at BGCAPP but at the BGAD facility.

option.[2] The BGAD open burning/open detonation site is currently operating under an interim status permit that allows treatment of 6 million pounds net explosive weight per year for the whole site. Open-burn pans are site-approved for 6,000 lb per event. So if 200 M55 rockets were cut each day, each with a propellant weight of about 20 lb, BGAD could carry out one 4,000-lb event every day and keep up with the pace of rocket motor accumulation (weather and other workload permitting). A proposal with some engineering design would be needed to test out base plate removal and propellant grain extraction. Standard operating procedures (SOPs) or SOP modifications would need to be written and approved for removal of the M28 propellant and the M62 rocket motor igniter assembly.

Since the M28 grain contains lead stearate, the environmental office would need to ensure that lead emissions remain within the permitted levels for their current air pathway hazards assessment for the amount of propellant to be burned. Although BGAD already has a Resource Conservation and Recovery Act (RCRA) Subpart X permit to dispose of waste energetics, the levels of lead in the M28 propellant grain could restrict the throughput of separated rocket motors.

The open burning of the propellant grain option would have the following advantages:

- There would be no need to modify the existing permit or apply for a new one, provided lead releases do not exceed permitted levels;
- If open-burning operations could keep pace with rocket cutting operations at BGCAPP, the need for a large volume of long-term storage would be eliminated;
- SOPs are in place for open burning, though a modified SOP might be needed for open burning of the M28 propellant grain;
- There would be a significant reduction in the risk of endangerment by eliminating the long-term storage of a hazardous material of unknown stability;
- The steel case could be readily inspected, the removal of all energetic materials verified, and the case certified as safe for recycling;
- The inert components could be accumulated for subsequent bulk disposal;
- During thermal destruction, deflagration (burning) of a confined energetic material could lead to an explosion or a transition to detonation. Removal of the propellant grain from the steel case would eliminate the tight confinement of the energetic material during thermal destruction; and
- If the M28 propellant was removed before thermal treatment, the concern about lead contamination of the metal components would be eliminated and metal components could be readily demilitarized and recycled as processed scrap metal.

The disadvantages of this option would include these:

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[2] Robotics strategies that have been developed for other conventional ordnance items could be applied if the propellant does not easily slide out. Sandia National Laboratories has developed such strategies.

- The removal of the propellant grain would entail greater handling of the separated rocket motors than a disposal option that disposed of the propellant grain while it was still within the motor case.
- Lead would be released into the local environment in the form of fine particulate matter. Over the course of treating 70,000 M55 rocket motors, the total potential quantity of lead released would exceed 3 tons. This might require the Kentucky Department for Environmental Protection (KDEP) to set constraints on treatment schedules to minimize the impact on the local population and the environment.
- The lead releases could restrict throughput of motors to fewer than the number that could be achieved based on net explosive weight limits.
- BGAD currently disposes of conventional ordnance under the Program Manager for Demilitarization. The rocket motor disposal workload would need to be synchronized with already existing open-burning commitments.

Finding 5-1. The Blue Grass Army Depot has a permitted, operational open-burning site that might be capable of meeting separated rocket motor disposal requirements.

Recommendation 5-1. If the option to burn the M28 propellant grain in the open is investigated, the Blue Grass Chemical Agent-Destruction Pilot Plant program staff should consult the Blue Grass Army Depot on its workload and determine if the open-burning unit could be available and easily scheduled for M28 propellant grain disposal.

Recommendation 5-2. Blue Grass Chemical Agent-Destruction Pilot Plant program staff should request an engineering design proposal for safely removing the M28 propellant grain from the rocket motor case to determine if the open-burning demilitarization option would be practical to implement.

Use of the Existing D-100 Detonation Chamber at BGAD

One alternative to open burning would be for BGAD to design upgrades to the D-100 detonation chamber already operational at BGAD although not currently in use. This chamber could be used to perform contained burn or static firing disposal operations. As currently designed, the D-100 detonation chamber is an explosive destruction technology, which is discussed in more detail in Chapter 3. CH2M HILL, the chamber manufacturer, and BGAD have proposed modifying this chamber to dispose of the separated rocket motors.[3] The throughput estimate is as high as 180 separated rocket motors per day for the D-100 (NRC, 2009).

In the event the rocket motor is unstable or if the propellant is cracked or degraded, a static fire could transition to detonation inside the chamber, damaging it and possibly putting it out of commission until cleared to operate again. In any case, damage to the chamber would accumulate in the course of normal operations, necessitating maintenance and periodic repairs.

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[3] The committee was not able to see the details of this proposal because they are competition sensitive.

As noted above, the M28 propellant contains lead stearate. As separated rocket motors are disposed of, lead compounds and residues would accumulate inside the chamber on walls and floors and on the metal scrap. Abatement activities such as lead monitoring and worker protection would be needed for personnel entering and working inside the chamber. The presence of lead on the metal scrap could also complicate the recycling of the metal scrap. The logistics associated with chamber cleanup and maintenance, motor stand preparation, and lead abatement activities will require an investment of time and resources to maintain the estimated throughput for this system.

The chamber would need to meet environmental and explosives safety criteria, and BGAD would need to obtain a RCRA hazardous waste permit modification for disposal of separated rocket motors in this chamber. Discussions with KDEP might result in operating the D-100 under interim status until a final permit is issued by the state. Obtaining these permits can be done within the time frame of the BGCAPP project if KDEP input is sought early in the decision process. Similar units have already been designed, installed, and used at other demilitarization sites to dispose of both conventional and chemical munitions. The Controlled Detonation Chamber, for instance, also manufactured by CH2M HILL, was used to dispose of recovered chemical warfare munitions at Schofield Barracks, Hawaii. This experience might ease the permitting process.

The use of the modified D-100 to dispose of the separated rocket motors would have the following advantages:

- All emissions and waste products from disposal would be contained.
- Detonation chambers similar to the D-100 have already been used to dispose of conventional and chemical munitions.
- The D-100 is already on-site and is undergoing permitting. Adapting it for separated rocket motor disposal would only entail modifications to the existing chamber and a permit modification.
- The entire separated rocket motor would be disposed of, requiring less handling of the motors than in the open burn option.

The use of the D-100 would have the following disadvantages:

- When factoring in maintenance, repairs, and unanticipated interruptions in processing, the projected throughput rate for the D-100 might not quite keep pace with the rate of separated rocket motor production at BGCAPP. This would entail the need for either more than one disposal unit, not necessarily a D-100, or the creation or securing of additional storage space on BGAD.
- Lead compounds will accumulate in the chamber over the course of operation, necessitating lead abatement and work protection activities.
- Lead will also accumulate on the metal scrap from separated rocket motor disposal, possibly complicating the recycling of this scrap.
- A separated motor transitioning to detonation during disposal could damage the chamber and have a significant impact on ongoing disposal operations and thus on schedule.

Alternative Disposal Technologies That Could Be Added to BGAD Capabilities

BGAD also has the option of contracting with a vendor to install a suitable disposal technology other than the D-100 on-site for separated rocket motor disposal. Several commercial units, discussed in Chapter 3 as explosive destruction technologies and treated in more detail in NRC, 2009, are available. Some of these have been used at other sites for chemical demilitarization operations.

The Kobe Steel DAVINCH is in use in Poelkapelle, Belgium, disposing of First World War-era munitions. It has been estimated that the DAVINCH DV120 could dispose of 36 separated rocket motors per day (NRC, 2009). The Dynasafe AB Static Detonation Chamber has been used at Anniston to augment destruction of munitions at the Anniston Chemical Agent Disposal Facility and is also in use in Munster, Germany, for disposing of First World War-era munitions. It has been estimated that an upgraded SDC 2000 could dispose of 100 separated rocket motors per day (NRC, 2009). This is not meant to be an exhaustive discussion, and other commercial firms, such as El Dorado Engineering, also provide contained disposal technologies that might possibly be used to dispose of the separated rocket motors.

Depending on the system design, multiple separated rocket motors could be treated simultaneously in a disposal unit. There would be a nominal setup time, but a long postfire period might be needed with some systems to allow rocket emissions to cool and settle before the chamber could be opened. All of these systems options are contained units and thus share the issues discussed above regarding the D-100. Contracting with a vendor to install a disposal unit could prove simpler than upgrading and retrofitting the current D-100 detonation chamber; it might also ease the permitting process if the vendor has experience in installing units in states other than Kentucky.

The advantages and disadvantages of any of these contained disposal technologies would be substantively similar to those for the D-100 enumerated above. One possible advantage is that, as mentioned above, contracting with a vendor to install, and perhaps operate, a technology that has already been successfully used in some way in the chemical demilitarization enterprise might be simpler from a permitting standpoint than modifying the D-100 and obtaining the necessary permit modification. A possible disadvantage is that the technologies for which estimated rates are available have throughput rates well below the planned rate of separated rocket motor generation at BGAD. This would mean having more than one of these units in operation and/or greatly expanded storage for the separated rocket motors.

Finding 5-2. There are alternative disposal technologies to open-burning that can be instituted at the Blue Grass Army Depot. However, the use of these alternative technologies would necessitate the inclusion of design, construction, and permitting time into the project schedule.

Finding 5-3. A D-100 detonation chamber is currently operational at the Blue Grass Army Depot to dispose of conventional munitions. It is possible that this could be modified and permitted to dispose of the separated rocket motors. A number of other contained technologies are available from commercial vendors, and it might prove simpler to contract for one of these to be installed than to modify the D-100 and obtain the necessary permit modification.

Finding 5-4. Use of any contained technology for the disposal of separated rocket motors would result in contamination of the chamber and any scrap metal with lead. This would necessitate lead abatement and worker protection activities and, possibly, complicate the recycling of metal scrap.

Disposal of Separated Rocket Motors at BGCAPP after Completion of All Chemical Agent Destruction Operations

Another option would be to store the separated rocket motors until all chemical agent destruction operations at BGCAPP are complete. The BGCAPP facility could then shift to the disposal of the separated rocket motors. The separated rocket motors could then be disposed of using the base hydrolysis technology already at BGCAPP and the same methodology as used for disposing of rocket motors contaminated with chemical agent. BGAD would need to confirm that is has enough safe storage capacity for all of the separated rocket motors on-site until all chemical agent disposal has been accomplished. This would lead to increased storage risk[4] compared to disposal of separated rocket motors concurrent with M55 rocket cutting operations at BGCAPP, as discussed in Chapters 2 and 4. The increased risk would be due to the normal issues associated with aging and degrading propellant as well as, perhaps, accelerated degradation of the separated rocket motors because they would be subject to greater environmental exposure than an assembled M55 rocket in its SFT. For this reason, the committee does not believe this is a good option.

Finding 5-5. The separated rocket motors could be stored and then disposed of using the BGCAPP base hydrolysis process after chemical agent destruction operations are complete. However, there is an increased storage risk inherent in this option.

Public Sentiment

While not an explicit item in the statement of task for the committee, public sentiment would have a significant impact on the ability to implement any chosen disposal technology or option (on-site versus off-site). The public has been very involved thus far in the choice of the technologies for use at BGCAPP and in all subsequent decisions involving BGCAPP, and it can be expected to be involved in this decision also. As such, the committee believes public sentiment needs to be considered. The public living and working around BGAD has historically been opposed to anything that resembles the incineration of the wastes from chemical munitions, of which the separated rocket motors are one, and it could have significant concerns about the disposal of the

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[4] *Storage risk* is defined in Appendix A.

propellant grain by open burning. The committee believes the public is likely to be sensitive to the issue of lead emissions from open burning.

Public sentiment has been evolving positively regarding the use of explosive destruction technologies (discussed in Chapter 3) and perhaps, by extension, of any contained disposal technology to process chemical munitions and the waste streams resulting from chemical demilitarization operations, of which the separated rocket motors are one. Contained disposal technologies also address the public's concerns about emissions to the environment.

While these considerations are not listed under the advantages and disadvantages of the on-site disposal options, the committee considers them worthy of mention and consideration. A historical overview of public sentiment about contained disposal technologies (specifically EDTs) and options (on-site versus off-site) can be found in Appendix B.

OFF-SITE[5] DISPOSAL OPTIONS

There are technically sound off-site disposal options for the separated rocket motors from BGCAPP. Using an off-site disposal option could free BGCAPP from having to choose a technology to dispose of the separated rocket motors. Indeed, the selection of the disposal technologies used may be a secondary factor when considering off-site disposal. Off-site disposal facilities might be able to use more than one technology concurrently to meet the schedule for the destruction of the energetic material in the separated rocket motors. One or more off-site facilities might be able to safely and efficiently conduct disposal operations in compliance with their respective site permits and regulatory requirements and within the project schedule. Overall, the off-site disposal of the rocket motors would allow for flexibility in the disposal technologies and strategies used.

One consideration regarding off-site disposal is that the motors of the M55 rockets are a unique propulsion system designed specifically for that rocket. It is thus unlikely that any off-site facilities have ever disposed of these specific separated rocket motors before. There are, however, likely facilities that have disposed of similar double-base propellant rocket motors in the past, so the uniqueness of the rocket motors from the M55 rockets might not be that much of an issue.

Separated rocket motors that have been cleared for transportation and disposal off-site would have to be received by facilities that are capable of meeting the disposal requirements, including any precautionary requirements that may be in place for disposing of munition components derived from chemical weapons. This could limit the number of off-site facilities that would be able to dispose of the separated rocket motors. Off-site facilities receiving the separated rocket motors would need to have a combination of sufficient permitted safe storage space and the disposal capacity to match the rate at which BGCAPP would ship the separated rocket motors.

Having an off-site government facility that already demilitarizes conventional munitions perform the separated rocket motor disposal work might be an option.

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[5] The committee is using *off-sit*e to indicate disposal away from the BGAD facility.

Although the separated rocket motors would have to be transported away from BGAD, they would be received by another government facility, and the communication channels and chain of command would all be within the government. This could expedite addressing any off-normal circumstances that might arise. Also, these installations already have the necessary environmental permits and explosive safety programs in place. Nonetheless, these demilitarization facilities also perform work for a variety of customers, so any request for the disposal of separated rocket motors would likely need to be coordinated with the demilitarization program offices having work performed there. In the Army several demilitarization sites dispose of rocket motors, including McAlester Army Ammunition Plant, Tooele Army Depot, and Anniston Army Depot.

A factor that might affect all off-site disposal options is the Chemical Weapons Convention. While the committee does not regard a separated rocket motor as a chemical munition, because the warhead containing the chemical agent will have been separated, the BGCAPP project management anticipates that demilitarization of the separated rocket motors will be required under the Convention.[6] For this reason, there could be inspection and monitoring requirements associated with the disposal of the separated rocket motors. International teams of inspectors might need to be allowed access to the disposal operations to verify the destruction of the separated rocket motors. This might impact the willingness of either a commercial or a government facility to receive and dispose of the separated rocket motors.

Finding 5-6. There are potential technologies for the disposal of the separated rocket motors that could be used concurrently at one or more off-site disposal facilities to meet program requirements and schedule. Off-site disposal would increase flexibility in regard to choice of a specific disposal technology. The Blue Grass Chemical Agent-Destruction Pilot Plant program staff would, of course, need to work with any off-site disposal facility to ensure that all relevant environmental regulations, such as the Resource Conservation and Recovery Act and the Toxic Substances Control Act, are complied with.

Recommendation 5-3. If off-site disposal is pursued, Blue Grass Chemical Agent-Destruction Pilot Plant program staff should allow off-site disposal facilities to tailor the mix of storage and disposal technologies that would allow for optimal, safe, and regulation-compliant disposal of the separated rocket motors.

Finding 5-7. There are government installations that currently conduct conventional munition demilitarization, including rocket motors. There might be advantages to having another government facility dispose of the separated rocket motors if off-site disposal is chosen.

Finding 5-8. Chemical Weapons Convention treaty requirements, such as inspection and verification of the disposal of the separated rocket motors, might affect the willingness of commercial or government off-site facilities to accept and dispose of the separated rocket motors.

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[6] E-mail from Jeff Krejsa, BGCAPP, to James Myska, study director, on April 25, 2012.

Public Sentiment

Again, while assessing public sentiment is not part of its task, the committee believes that such sentiment will impact the ability to implement any disposal option for the separated rocket motors. The public around BGAD has a history of being sensitive to transporting off-site any secondary wastes from chemical demilitarization, of which the separated rocket motors are an example. Over time, it has proved willing to consider shipping categories of secondary wastes off-site on a case by case basis, but only if there is a sufficient justification. One factor that could cause the public to be willing to consider off-site transportation is safety, although this might leave unresolved other factors such as potential impacts on receiving communities and communities along shipping routes. If it would be safer to move a given waste off-site than to dispose of it on-site, the public may be willing to consider such an option. However, history points to the likelihood that the public will be much more accepting of an on-site disposal option. This is discussed in more detail in Appendix B.

SHIPPING AND FIRING TUBE MANAGEMENT

One of the wastes from disposing of the separated rocket motors will be the SFTs, which will constitute a waste stream distinct from the separated rocket motors. The SFTs contain on average approximately 1,250 ppm of polychlorinated biphenyls (PCBs).[7] This is based on trial burns conducted at the Deseret Chemical Depot (Kimmel et al., 2001). PCBs are semivolatiles that readily penetrate the skin and are fat soluble. The National Institute for Occupational Safety and Health has issued guidance on workplace exposure to PCBs (NIOSH, 1977).

When items containing more than 50 ppm of PCB are declared to be a waste, the Toxic Substances Control Act (TSCA) PCB disposal regulations in Subpart D of 40 CFR 761 come into play, requiring PCB containing items to be disposed of in a TSCA-compliant incinerator, in a TSCA-compliant chemical waste landfill, or by an EPA-approved alternative method. As a result of the M55 rocket disposal operations, BGCAPP will be a generator of PCB waste as defined in 40 CFR 761.3. Since there are no liquid PCB wastes it may be possible that the SFTs could be considered a PCB bulk waste, defined as a

> waste derived from manufactured products containing PCBs in a non-liquid state, at any concentration where the concentration at the time of designation for disposal was ≥50 ppm PCBs. PCB bulk product waste does not include PCBs or PCB Items regulated for disposal under §761.60(a) through (c), §761.61, §761.63, or §761.64. (40 CFR 761.3)

If SFTs can be classified as PCB bulk waste they could possibly be disposed of in a permitted non-hazardous-waste landfill, though this would need to be ascertained (40 CFR 761.62). If the SFTs cannot be designated as PCB bulk waste, they would have to be

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[7] Kevin Regan, environmental manager, BGAPP project, “Rocket Motor (RM) Disposal,” briefing to the committee, March 20, 2012.

treated like any other PCB article, as defined in 40 CFR 761.3, and would have to be disposed of as specified in 40 CFR 761.60.

BGAD does not currently have a facility permitted to dispose of PCBs, so treating or disposing of the SFTs on-site would be very challenging. The open burning of any materials containing PCBs is not permitted (40 CFR 761.50(a)(1)). Thus if an open disposal technology was selected to dispose of the separated rocket motors, the motors would in any case have to first be removed from their SFTs. Even when using a contained combustion disposal technology, if the separated rocket motors were not first removed from their SFTs, the waste streams would be contaminated with PCBs and the systems that treated the off-gases from these technologies would have to be able to handle the PCB loading. Additionally, to dispose of the SFTs on-site, BGAD would have to obtain a TSCA permit. For all of these reasons, the committee does not envision the separated rocket motors being disposed of while still in their SFTs.

Once the separated rocket motors are removed from their SFTs, the SFTs no longer need to be stored as an energetic material, and become subject to the regulations governing the storage and transportation of PCB-containing materials. Items with PCB concentrations 50 ppm or higher must be stored in accordance with 40 CFR 761.65. This includes a requirement to destroy or dispose of these items within 1 year after their removal from service, and may restrict storage time to less than 1 year. One-year extensions are available.

Finding 5-9. Disposing of the separated rocket motors while they are still in the shipping and firing tubes would contaminate the resulting waste streams with polychlorinated biphenyls.

Recommendation 5-4. The separated rocket motors should be removed from their shipping and firing tubes prior to disposal.

Finding 5-10. The storage, disposal, or treatment of the shipping and firing tubes, which contain polychlorinated biphenyls, on-site would be very challenging and subject to the Toxic Substances Control Act and Subpart D of 40 CFR 761.

Recommendation 5-5. The shipping and firing tubes should not be disposed of or treated on-site. Any on-site disposal plan should include sending the shipping and firing tubes off-site to a licensed commercial facility that complies with the Toxic Substances Control Act and Subpart D of 40 CFR 761. Attention should be paid to the regulations governing the storage and transportation of shipping and firing tubes after they are removed from the separated rocket motors. These regulations impose time limits on the storage of polychlorinated biphenyl-containing wastes.

If off-site disposal is selected for the separated rocket motors, then the off-site facility could assume responsibility for the transportation, storage, and ultimate disposal of the SFTs. Still, the SFTs would have to be transported in compliance with the appropriate TSCA regulations, and the receiving off-site facility would have to be compliant with TSCA and Subpart D of 40 CFR 761. The receiving off-site facility would need to be made aware of the PCBs in the SFTs.

Finding 5-11. If off-site disposal is selected for the separated rocket motors, the receiving facility would have to be compliant with the Toxic Substances Control Act and Subpart D of 40 CFR 761 and would need to be informed of the presence of polychlorinated biphenyls in the shipping and firing tubes.

Recommendation 5-6. When exploring off-site options for the disposal of the separated rocket motors, the Blue Grass Chemical Agent-Destruction Facility Pilot Plant project management should ensure that potential receiving facilities are aware of the presence of polychlorinated biphenyls in the shipping and firing tubes. They should also ensure that any facilities selected are compliant with the Toxic Substances Control Act and Subpart D of 40 CFR 761.

TRANSPORTATION OF SEPARATED ROCKET MOTORS

On-site Transportation of Separated Rocket Motors

Once cleared through headspace monitoring at BGCAPP, the separated rocket motors will be transferred to temporary storage in the BGCAPP munitions demilitarization building. At this point, they could also be transferred to BGAD from the munitions demilitarization building temporary storage. This transfer would need to follow the requirements of the following regulations:

- Army Regulation 385-64, U.S. Army Explosives Safety Program (U.S. Army, 1997);
- Army Regulation 385-10, The Army Safety Program (U.S Army, 2011a);
- Department of the Army Pamphlet 385-64, Ammunition and Explosives Safety Standards (U.S. Army, 2011b); and
- Army Regulation 55-355, Defense Traffic Management Regulation (U.S. Army, 1986).

The separated rocket motors will be RCRA-regulated explosive hazardous waste based on the RCRA definition of reactive material (EPA Hazardous Waste Code: D003) and based on toxicity related to lead (EPA D008-lead). As long as the rocket motors remain on-site, RCRA transportation requirements will not be triggered. Thus, the RCRA definition of *on-site* is important. Transportation of hazardous wastes within a geographically contiguous property, including property divided by roads, is considered on-site as long as the wastes are not transported along a public right-of-way. On-site transportation would also significantly reduce the risk to safety presented by off-site transportation of a hazardous material of unknown stability because BGAD would be able to positively control traffic on the depot to ensure unrelated personnel are kept away from the separated rocket motors during transport, and they would not be transported on public rights of way.

The separated rocket motors may also have been assigned a Kentucky state waste code (N001 or N002) because they are derived from chemical weapons. Transportation off-site of materials bearing these waste codes would likely be subject to regulatory restrictions, so it might be more straightforward to accomplish on-site transportation than to transport the materials off-site.

An important factor that will affect on-site transportation–and off-site transportation also–is the hazard classification of the separated rocket motors. This classification will affect packaging and transportation requirements. The hazard classification of the separated rocket motors is discussed in Chapter 2.

Finding 5-12. Transporting separated rocket motors solely on-site will be safer and easier to accomplish than transporting separated rocket motors off-site.

Off-site Transportation of Separated Rocket Motors

Under Subtitle C of RCRA, a hazardous waste transporter is any entity that transports hazardous waste off-site within the United States, if a manifest is required. These regulations establish requirements for hazardous waste handlers; transporters; and treatment, storage, and disposal facilities.

Transporting separated rocket motors off-site will require compliance with a variety of regulations and coordination with all state regulatory entities along the planned route. There are other requirements for transporting the separated rocket motors, including having an Environmental Protection Agency identification number, transfer facility requirements, manifesting and record keeping, and establishing actions to be taken in the event of hazardous waste discharges or spills. The following documents cover pertinent aspects of the transportation of energetic hazardous wastes and are important references.

- Title 40 of the Code of Federal Regulations, Part 262, Subparts B and C, which address manifesting and pretransportation requirements for hazardous wastes.
- Title 40 of the Code of Federal Regulations, Part 263, which sets out the standards applicable to hazardous waste transporters.
- Title 40 of the Code of Federal Regulations, Part 761, Section 207, which addresses the requirements for transporting wastes containing PCBs. This would apply to the transportation of the SFTs.
- Title 49 of the Code of Federal Regulations, Subtitle C, Hazardous Materials Regulations, issued by the Pipeline and Hazardous Materials Safety Administration. These govern the transportation of hazardous materials by highway, rail, vessel, and air.[8]
- Part II of the Defense Transportation Regulation, which stipulates that the movement of regulated hazardous materials must comply with the rules of regulatory bodies governing the safe transportation of regulated hazardous

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[8] See http://ecfr.gpoaccess.gov/cgi/t/text/text- idx?sid=69820f56014d9312d67ea8169b0e9e01 &c=ecfr&tpl=/ecfrbrowse/Title49/49tab_02.tpl.

materials for selected modes of transportation, which includes ammunition, explosives, and munitions (DoD, 2008a).
- Department of the Army Pamphlet 385-64, which describes the Army's safety criteria and standards for operations involving ammunition and explosives (U.S. Army, 2011).
- DoD Ammunition and Explosives Safety Standards, which set uniform safety standards for ammunition and explosives throughout their entire life cycle. The purpose of these standards is to protect personnel and property, whether related or unrelated, and the environment from the potential damaging effects of an accident involving ammunition and explosives (DoD, 2008b).
- DoD Contractor's Safety Manual for Ammunition and Explosives, which contains requirements and provides guidance for safety, storage, site requirements, and operations involving ammunition and explosives (DoD, 2008c).

As noted previously, the separated rocket motors might also bear a Kentucky state waste code (N001 or N002) because they are derived from chemical weapons, and transportation of materials carrying these waste codes off-site would therefore likely be subject to additional regulatory restrictions.

Finding 5-13. All off-site disposal options necessarily require removal of the separated rocket motors from government property and transportation on public roads or railways. There are numerous federal, state, and Army regulations governing the transportation of explosive hazardous waste, permits, and safety standards that must be met.

Transportation on public roads will require packaging these hazardous components in performance-oriented packaging (POP) designed and tested to meet the requirements of the U.S. Department of Transportation 49 CFR 178 (U.S. Army, 2008).[9] These POP tests are conducted to ensure the packaging materials and design can withstand the anticipated stresses of the shipping environment simulated by a series of tests, including drop, stack, and vibration tests. It should be noted that large quantities of propellants, explosives, assembled and disassembled ammunition, pyrotechnics, fireworks, and a wide variety of other energetic materials and ingredients are routinely and safely transported on public roads and railways without incident following Department of Transportation regulations using well-established methods.

The U.S. Army Materiel Command Logistics Support Activity Packaging, Storage, and Containerization Center at Tobyhanna, Pennsylvania, provides guidance on the procedures to be followed when performing packaging testing, including test sample procedures, scheduling, and test report format to ensure that the proposed packaging materials and designs are capable of passing all applicable tests prescribed in the Hazardous Materials Regulations in 49 CFR 178 (U.S. Army, 2008).

Finding 5-14. Transportation of separated rocket motors off-site must comply with federal regulations governing the transportation of hazardous materials on public

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[9] More information can be found via https://www.logsa.army.mil/pscc/PSCC_WebDev/PSCC/psccindex.htm.

thoroughfares, including the use of labeled performance-oriented packaging, which is packaging that has been tested to meet anticipated environmental and transportation stresses.

Finding 5-15. Performance-oriented packaging does not exist for the off-site transportation of the separated rocket motors. Such packaging would have to be designed and certified prior to use. This is a time-consuming and expensive process.

ADVANTAGES AND DISADVANTAGES OF ON-SITE SEPARATED ROCKET MOTOR DISPOSAL

On-site disposal of the separated rocket motors at BGAD would be carried out near the site where the separated rocket motors originate and on property contiguous to the treatment site. This alternative offers many advantages:

- The explosives safety risk is minimized by having a short transportation path from point of separated rocket motor generation and storage to the disposal site. Being on contiguous property eliminates the hazards of transporting explosive hazardous waste over public roads, keeps the explosive safety hazards away from populated areas, and reduces the burden of transportation regulatory compliance requirements. For instance, on-site transportation would be exempt from RCRA transportation requirements, though it would not be exempt from installation explosive safety and hazardous waste management requirements.
- BGAD is currently one of the demilitarization installations funded under the Conventional Ammunition Demilitarization Program and has experience in munitions demilitarization and explosive hazardous waste treatment and disposal. BGAD has a munitions scrap metal program. The metal rocket motor cases and other metal scrap recovered from disposal operations can be included in the Demilitarization Enterprise scrap metal cost recovery program, whereby the revenues obtained by this means are returned to the demilitarization account.
- BGAD has a permitted open-burning disposal site that might be able to meet the disposal requirements for the separated rocket motors.
- BGAD already has a RCRA Subpart X permit for disposal of explosive hazardous waste. This permit could be amended to include a modification for one or more contained units to dispose of separated rocket motors.
- A D-100 CH2M Hill controlled detonation unit is already installed at BGAD for the destruction of conventional weapons. The possibility of adapting this technology to destroy separated rocket motors by static firing has been proposed to BGCAPP by CH2M HILL and BGAD.
- Installing an alternative technology to open burning could leave a residual capability that BGAD could then use for future work.

- The public living and working around BGAD is likely to be much more accepting of an on-site disposal option.

The disadvantages of on-site demilitarization include these:

- The projected throughput of any on-site disposal technology other than open burning would likely barely meet or not meet at all the planned rate of separated rocket motor generation at BGCAPP without the use of multiple units.
- Open burning has as its main disadvantage the release of lead from the propellant into the environment. If a contained disposal technology were selected, there would likely be a need for more than one contained disposal system, or increased on-site storage, or both.
- The alternative technologies have yet to be put in place, so time and funds would be needed to select and install an alternative technology and obtain the necessary permits or permit modifications.
- BGCAPP and BGAD would be responsible for the disposal of all resulting waste streams, including the SFTs, which contain PCBs and are regulated under TSCA.

ADVANTAGES AND DISADVANTAGES OF OFF-SITE SEPARATED ROCKET MOTOR DISPOSAL

The off-site disposal of all of the separated rocket motors may offer some advantages over on-site disposal:

- Off-site disposal would relieve BGCAPP and BGAD of the many of the day-to-day planning and logistics tasks that would be associated with on-site disposal.
- It would also allow flexibility in the choice of technology to dispose of the separated rocket motors. Indeed, a specific technology or technologies might not have to be chosen by BGCAPP project management.
- Off-site disposal could significantly mitigate any need for increased storage space for the separated rocket motors on BGAD.
- The disposal contractor would be responsible for the disposal of all waste streams, including the SFTs.
- There are well-equipped and -staffed off-site facilities that can dispose of the separated rocket motors with minimal start-up time and delay.
- If all separated rocket motors were sent off-site for disposal, BGAD would not need to establish, modify, or expand any rocket motor disposal facility and the associated permits.

There are a number of disadvantages to the off-site disposal option:

- Transportation of the rocket motors off-site would require compliance with a large body of federal regulation that would not be operative for transportation and disposal wholly on-site at BGAD, as discussed above. Also, should transportation across state lines become necessary, this could necessitate coordination with the appropriate state regulatory bodies along the route.
- An important factor in off-site transportation is public sentiment. Historically, any transport of waste material derived from chemical weapons, such as the separated rocket motors, away from a depot site has become a matter of significant public concern. Selecting an off-site disposal option and transporting the separated rocket motors off-site would open the possibility of public action, slowing the process of transporting and disposing of the separated rocket motors. This could pose a significant schedule risk.
- Another disadvantage of an off-site disposal option is that safe transportation requires POP-certified packaging for the separated rocket motors. Such packaging does not currently exist for the separated rocket motors. The currently planned storage and transportation box for the separated rocket motors would only be usable for on-site transportation at BGAD. The effort to design, produce, and obtain certification for the necessary POP-certified packaging would be both time-consuming and expensive.
- The BGCAPP project management anticipates that the demilitarization of the separated rocket motors will be a treaty requirement under the Chemical Weapons Convention. Any off-site facility that disposed of the separated rocket motors might therefore have to accept inspection and verification. This might impact the willingness of an off-site facility to accept and dispose of the separated rocket motors.

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Appendixes

Appendix A
Glossary

Demilitarization The act of rendering something useless for any military purpose. The act of destroying the military offensive or defensive advantages inherent in certain types of equipment or material. The term includes mutilation, dumping at sea, cutting, crushing, scrapping, melting, burning, or altering; [demilitarization is] designed to prevent the further use of this equipment and material for its originally intended military or lethal purpose. The term applies equally to material in unserviceable or serviceable condition that has been screened through an inventory control point and declared surplus or foreign excess (DLA, 2004).

Disposal The elimination of rocket motors by any means, e.g., demilitarization, destruction, recycling. End of life tasks or actions for residual materials resulting from demilitarization or disposition operations (DoD, 2010). The process of reutilizing, transferring, donating, selling, destroying, or other ultimate disposition of personal property (DLA, 2004).

Off-site Disposal of rocket motors away from the Blue Grass Army Depot at a commercial or a government facility.

On-site Disposal of rocket motors at the Blue Grass Army Depot.

Separated rocket motor The entire section of an M55 rocket aft of the warhead, after separation by the rocket cutting machine. Includes the motor case, propellant, fins and various miscellaneous parts, and the fore closure.

Storage risk The risk of an adverse incident in storage. As applied to chemical weapons it refers mainly to the risk of a chemical agent leak developing. As applied to the M55 rockets it refers mainly to the risk of an autoignition event in a storage igloo or magazine due to propellant degradation.

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Appendix B

Historical Overview of Public Sentiment Surrounding the Blue Grass Army Depot and the Blue Grass Chemical Agent-Destruction Pilot Plant Relevant to the Disposal of Separated Rocket Motors

A review of public sentiment was not part of the committee's task. To the extent that public sentiment is included in this report, it is included only insofar as it might impact decisions about how to dispose of the rocket motors separated from M55 rockets stored at the Blue Grass Army Depot (BGAD). The reason for inclusion is that history demonstrates that public sentiment can have a very significant effect on the ability to implement any technical decisions in the context of the disposal of chemical munitions and their associated wastes.

The purpose of this appendix is to establish the basis for the committee's speculation, expressed in the body of the report, about how the public around BGAD might react to decisions made on disposing of the separated rocket motors. It is important to note that the committee did not speak to the public, as it was not tasked to do so. It is also important to understand that none of what follows expresses the committee's opinions; rather, it constitutes a reporting of historical public positions the committee believes are pertinent to the topic of this report.

HISTORICAL OVERVIEW OF PUBLIC SENTIMENT REGARDING THE SELECTION OF TECHNOLOGIES FOR USE AT BGAD

Surrounding communities have a long history of interest and active involvement in plans to dispose of chemical weapons stored at BGAD. Indeed, opposition to incineration was a key factor leading to creation of the original Assembled Chemical Weapons Assessment program and the choice of a nonincineration technology for the destruction of chemical agent and associated wastes at BGAD and the Pueblo Chemical Depot. Consequently, activist members of the Kentucky Chemical Demilitarization Citizens' Advisory Commission (CAC) and Chemical Destruction Community Advisory Board (CDCAB), which represent the local public,[1] have shared an opposition to

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[1] For a detailed description of the composition and role of the CAC and CDCAB, see NRC (2008). The two groups, which at that time were operating somewhat independently, now meet together on a quarterly basis. Meeting summaries and recommendations are available at http://www.pmacwa.army.mil/bgcapp/bgcapp_public_involvement.html.

incineration. They also share the belief that the Record of Decision,[2] which specified neutralization followed by SCWO as the technologies for Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP), represents a "commitment to the community" to use those technologies to dispose of as much material on-site as possible (NRC, 2008).[3]

In opposing incineration, activist groups established criteria by which they judge alternative technologies for destroying not only chemical weapons but hazardous wastes in general. Among these criteria are:

- Containment of all by-products,
- Identification of all by-products,
- No uncontrolled releases, and
- A series of criteria pertaining to worker safety (Crowe and Schade, 2002).

In 2006, following the fires experienced during M55 rocket shearing operations at the Umatilla and Pine Bluff Chemical Agent Disposal Facilities, the CDCAB Secondary Waste Working Group met and was briefed by the Non-Contaminated Rocket Motors Integrated Process Team, which presented options on behalf of the Bechtel Parsons Blue Grass Team for the disposal of separated rocket motors.[4] Three options were presented:

- On-site nondeflagration technologies–for example, (1) caustic hydrolysis of the propellant, followed by supercritical water oxidation (SCWO), (2) wet grinding of the propellant followed by SCWO, and (3) caustic hydrolysis of the propellant, followed by biotreatment of the energetics hydrolysates;
- On-site deflagration technologies–for example, (1) contained static fire, (2) contained burn, and (3) use of a Static Detonation Chamber (SDC)[5]; and
- Off-site processes–for example, (1) caustic hydrolysis of the propellant and the off-site disposal of the energetic hydrolysates, (2) wet grind of the propellant, followed by off-site recycling, and (3) incineration.
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Among these options, the CDCAB is on record as recommending, in order of preference, the following:

- On-site caustic hydrolysis of the propellant followed by treatment of the hydrolysates by industrial SCWO and
- Off-site recycling of the propellant at a government facility (CDCAB, 2006).
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[2] Record of decision, Chemical Stockpile Disposal Project, destruction of the chemical agents and munitions stored at Blue Grass Army Depot, Kentucky, signed by Raymond J. Fatz, Deputy Assistant Secretary of the Army (Environment, Safety, & Occupational Health), dated February 27, 2003.

[3] As noted in NRC, 2008, public sentiment is not uniform: the CAC and CDCAB may not represent the totality of public sentiment, and a substantial portion of the community was reported in that study as simply supporting prompt elimination of the chemical agent stockpile.

[4] The Bechtel Parsons Blue Grass Team is the team of contractors who designed, are building, and will operate, close, and dismantle BGCAPP.

[5] This technology, from the vendor Dynasafe AB, is discussed in Chapter 3.

Subsequently, the joint CAC/CDCAB added another recommendation to continue studying the use of the SDC for only those rocket motors that are not contaminated by chemical agent, based on the SDC "emerging as a new, on-site treatment option" (CDCAB, 2007).

More recent discussion in the public record focused on disposal of the rocket motors is limited. No recent public record is available regarding use of any nonhydrolysis technologies (i.e., any technologies other than those already in the BGCAPP design) other than an explosive destruction technology (EDT). An EDT Working Group[6] examined the possible use of four types of EDT for disposing of three categories of items, including separated rocket motors that had not been contaminated with chemical agent. The four EDTs considered were these:

- The Transportable Detonation Chamber (from CH2M HILL);
- The Detonation of Ammunition in a Vacuum-Integrated Chamber) (DAVINCH) (from Kobe Steel, selected for use at the Tooele Chemical Agent Disposal Facility, though not for separated rocket motors);
- The SDC (from Dynasafe AB, at that time selected for use at the Anniston Chemical Agent Disposal Facility, again, not for separated rocket motors); and
- The EDS (produced by Sandia National Laboratories for the Program Manager for Non-Stockpile Chemical Materiel).

Since 2009, the CAC/CDCAB has issued two sets of positions or recommendations concerning use of an EDT at the BGCAPP, or at BGAD in support of BGCAPP operations. First, in December 2009, the CAC/CDCAB indicated that they would be willing to consider the use of an EDT to dispose of three categories of munitions, including separated rocket motors that had not been contaminated with chemical agent. They did place a number of caveats on this position, including

- Reserving the endorsement of any EDT until its capabilities and compliance with Kentucky state environmental regulations had been demonstrated to the satisfaction of the CAC/CDCAB;
- Insisting on playing an active role in the prioritization of evaluation criteria for selecting an EDT;
- Using an EDT to dispose of any actual nerve agent, such as contaminated rocket parts, is absolutely opposed, with the possible exception of overpacked nerve agent munitions and nerve agent munitions in a condition that would required significant handling to process through BGCAPP; and

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[6] This group was originally established in 2009. It was reestablished in 2011 at the request of the BGCAPP site project manager, who noted that "several factors are important to the destruction process selection, the current design has limitations of unknown capacity and the ACWA Program will work with the EDT Working Group to receive input on considerations for the final EDT decision" (CDCAB, 2011, p. 6). The site project manager's presentation to the CAC/CDCAB of the EDTs in December 2011 as a "potential method to augment the basic destruction plans for BGCAPP" (CDCAB, 2011, p. 6) is available on the Web site. However, as of this writing, the related CAC/CDCAB discussion had not yet been posted.

- Bringing permitting issues to the public's attention in a timely manner, even going beyond the letter of what the law requires, to ensure that the public is adequately involved in the permitting process (CDCAB, 2009).

Second, in January 2012, following re-formation of the EDT Working Group, the CAC/CDCAB issued another recommendation on the use of the EDT at BGCAPP. They recommended its use to dispose of "problem" mustard heels, with caveats similar to those articulated in their 2009 statement (above) and with the addition of the following comments:

- The KY CAC/CDCAB believes the deployment and use of the EDT at the Anniston Chemical Demilitarization Facility (ANCDF) fulfills many of the requirements of KRS 224.50-130 (3) (a)). However, there remain questions concerning whether the experience at Anniston sufficiently demonstrates the ability to meet the following requirement within the section: "During the occurrence of malfunctions, upsets, or unplanned shutdown, all quantities of any compound listed in subsection (2) of this section shall be contained, reprocessed or otherwise controlled so as to ensure that the required efficiency is attained prior to any release to the environment." (CDCAB, 2012, pp. 1-2)
- The CAC/CDCAB wants to see a "continuous investigation of the hold-test-release capabilities of potential agent emissions with any EDT considered for the Blue Grass disposal effort, while recognizing that such investigations should not be allowed to significantly impact EDT deployment." (CDCAB, 2012, p. 2)

These more recent recommendations indicate provisional support for the use of an EDT for very specific applications on the part of organized public groups, specifically when they deem it is warranted to reduce the risk to workers and are convinced that the process can be conducted safely and in compliance with Kentucky regulations. Consequently, the use of an EDT for the separated rocket motors might prove acceptable to the public. Still, there are many caveats and conditions, and it is clear that further engagement with the public groups around BGAD will likely be necessary to ensure that they are comfortable with the use of an EDT or other contained disposal technology to dispose of separated rocket motors at BGAD.

HISTORICAL OVERVIEW OF PUBLIC SENTIMENT ON THE ISSUE OF ON-SITE VERSUS OFF-SITE DISPOSAL

Separated rocket motors would be a waste derived from a chemical munition. Public sentiment about where the wastes derived from chemical munitions should be disposed of is closely intertwined with support for the technology selection of hydrolysis followed by SCWO, identified in the 2003 Record of Decision.[7] A joint Colorado and Kentucky CAC public statement emphasized that their long-standing opposition to shipment off-site of any wastes derived from chemical agent or munitions is based on a number of factors, including the following:

- A perception on the part of the CACs of increased risks associated with transporting these wastes off-site;
- Concern about possible opposition from communities that would be receiving wastes;
- Concern about a negative economic impact on the communities around BGAD and the Pueblo Chemical Depot;
- Political opposition;
- The possibility of litigation;
- Concern about a risk of violating the site's Resource Conservation and Recovery Act permit by changing the permitted processes; and
- The CACs' concern about possibly violating environmental justice principles;[8] and
- The elimination of a potential legacy use for on-site treatment facilities that would be left over at BGAD following the completion of BGCAPP operations. (CAC, 2008).
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Members of the Kentucky and Colorado CACs have expressed the intent to use political influence, the permitting process, and legal action to prevent, or at a minimum delay, the program schedule in the event of a decision to implement off-site shipment of secondary wastes, of which separated rocket motors are one example (NRC, 2008).

Nevertheless, as with treatment technologies, the CAC/CDCAB has been willing to recognize the need for flexibility when faced with countervailing arguments, especially those concerning potential risks to workers and the general public. In fact, when Operation Swift Solution[9] was implemented to dispose of three leaking ton containers of GB, the shipment of the resulting hydrolysates off-site was approved as a necessary measure for safety reasons. Still, the CAC/CDCAB is on record as stating as follows:

> Tolerating this one time, off-site shipment of material the CAC/CDCAB does not in any way imply support for, the condoning of, or even consideration of any future similar shipments of similar materials off site associated with the Blue Grass Chemical Agent Pilot Plant (BGCAPP). (CDCAB, 2008, p. 1)

So, while it is clear that there are circumstances in which the local public organizations will tolerate the shipment off-site of wastes resulting from the disposal of chemical

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[7] Record of decision, Chemical Stockpile Disposal Project, destruction of the chemical agents and munitions stored at Blue Grass Army Depot, Kentucky, signed by Raymond J. Fatz, Deputy Assistant Secretary of the Army (Environment, Safety, & Occupational Health), dated February 27, 2003.

[8] There is a concern that receiving communities and communities along shipping routes may already be economically disadvantaged and thus subject to environmental injustice by wastes from BGCAPP.

[9] For more information on Operation Swift Solution, see https://www.pmacwa.army.mil/bgcapp/swift_solution.html.

munitions, such toleration is accompanied by caveats and a significant level of concern. It can be anticipated that any proposal to transport separated rocket motors off-site for disposal will meet a similar level of concern from the public organizations around BGAD unless they can be satisfied of the necessity for such a course of action and its safety.

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Appendix C
Committee Activities

FIRST COMMITTEE MEETING
MARCH 20-22, 2012

RICHMOND AND LEXINGTON, KENTUCKY

Objectives: To introduce required administrative procedures set forth by the National Research Council, conduct the composition and balance discussion, read the committee statement of task and background review with committee sponsor, receive briefing presentations on rocket motor disposal, review preliminary report outline and report-writing process, flesh the report outline out into a concept draft, confirm committee writing assignments, and discuss next steps and future meeting dates.

Blue Grass Chemical Agent-Destruction Pilot Plant, Jeff Brubaker, Site Project Manager
U.S. Army Element, Assembled Chemical Weapons Alternatives Blue Grass Chemical Agent Destruction Pilot Plant Office

Rocket Motor Disposal, Kevin Regan, Bechtel Parsons Blue Grass Team

VIRTUAL MEETING
APRIL 27, 2012

Objective: To discuss the study's progress and path forward.

SECOND COMMITTEE MEETING
MAY 8-10, 2012

WASHINGTON, D.C.

Objectives: To conduct committee deliberations, discuss report status, conduct report drafting to achieve a preconcurrence draft, and make any necessary final work assignments.

THIRD COMMITTEE MEETING
JUNE 27-28, 2012

WASHINGTON, D.C.

Objectives: To discuss preconcurrence draft, achieve committee concurrence.

Appendix D

Biographical Sketches of Committee Members

Randal J. Keller is currently a professor in the Department of Occupational Safety and Health at Murray State University, Kentucky. He received a B.A. in chemistry from Eisenhower College in 1979; an M.S. in toxicology from Utah State University in 1984; and a Ph.D. in toxicology, also from Utah State University, in 1988. He is certified in the comprehensive practice of industrial hygiene by the American Board of Industrial Hygiene, in the comprehensive practice of safety by the Board of Certified Safety Professionals, and in the general practice of toxicology by the American Board of Toxicology. Dr. Keller is widely published and maintains an independent consulting practice related to toxicology, industrial hygiene, and safety. He served on the NRC's Committee to Review and Assess Industrial Hygiene Standards and Practices at Tooele Chemical Agent Disposal Facility (TOCDF), the Committee on Evaluation of Safety and Environmental Metrics for Potential Application at Chemical Agent Disposal Facilities, and the Committee on the Assessment of Process Safety Metrics for the Blue Grass and Pueblo Chemical Agent Destruction Pilot Plants.

Judith A. Bradbury is an independent consultant who recently retired from the Pacific Northwest National Laboratory. She has extensive experience in the research and practice of public involvement in hazardous technologies. Her work includes management of a series of evaluations of the U.S. Department of Energy's (DOE's) site-specific advisory boards and an assessment of community perspectives on the U.S. Army Chemical Weapons Disposal program. Her most recent experience was in managing public outreach activities for the Midwest Regional Carbon Sequestration Partnership Program, sponsored by DOE. She has coauthored several research reports on communication and engagement, including identification of factors contributing to effective engagement in carbon capture and storage. She is currently a member of the European ECO_2 Scientific Advisory Board. Dr. Bradbury was initially educated in the United Kingdom and has a degree in sociology from the London School of Economics. Subsequently, she earned an M.A. in public affairs from Indiana University of Pennsylvania and a Ph.D. in public and international affairs from the University of Pittsburgh.

Randall J. Cramer is an environmental protection specialist at the Ordnance Environmental Support Office of the Naval Ordnance Safety and Security Activity. Dr. Cramer has a multidisciplinary background and broad research experience in government, academia, and private industry. He provides technical expertise in munitions and ordnance environmental research and development, military munitions demilitarization recycling and reuse, pollution prevention in ordnance development and manufacturing. He also performs U.S. Navy explosives safety inspections to ensure navy installations are in environmental compliance with explosive hazardous waste management regulations. Dr. Cramer currently chairs the Joint Ordnance Commanders Group Environmental Subgroup and is a member of the Joint Army-Navy-NASA-Air Force Safety and Environmental Subcommittee and is the Navy representative on the Interagency Committee on Explosives. He supports the Navy on the Clean Air Act, the Resource Conservation and Recovery Act (RCRA), and EPCRA/TRI Services steering committees. He has given numerous presentations to the technical community, published several papers, and is the inventor for eight patents.

Eric D. Erickson is a senior scientist in the Energetics Research Division of the Weapons and Energetics Department at the Naval Air Warfare Center in China Lake, California, where he provides technical support for several weapons program offices. Before that, Dr. Erickson was a principal investigator in the Instrumental Analytical Chemistry Branch in the Research and Intelligence Department at the Center. His research activities have included the development of several ordnance demilitarization technologies and the monitoring of their emissions. Dr. Erickson received a B.S. in chemistry from Oregon State University and a Ph.D. in analytical chemistry from Michigan State University. He also has a certificate of achievement in industrial hygiene from San Diego City College.

Brad E. Forch has been the Army Chief Scientist for Ballistics (ST) for the Weapons and Materials Research Directorate at the U.S. Army Research Laboratory since January 2009. His research expertise is in a wide range of ballistics, including developing the fundamental understanding of chemical and physical mechanisms controlling chemical energy storage, ignition, combustion, and release in propellants, explosives, and novel energetic material structures for weapons applications. He was the chief of the Propulsion Science Branch in the Ballistics and Weapons Concepts Division of the Weapons and Materials Research Directorate from 2000 to 2009 and chief of the Ignition and Combustion Branch in the Propulsion and Flight Division of the Weapons Technology Directorate from 1995 to 2000. As a supervisory research physicist, Dr. Forch was responsible for the direction of a wide range of basic and applied scientific research and concept development activities in ballistics, energetic materials, novel propellants and explosives, nanoenergetic materials, reactive materials, and ignition and combustion research. He served as a research scientist and team leader from 1986 to 1995 in the Interior Ballistics Division of what was then the U.S. Army Ballistic Research Laboratory (BRL). His work focused on research leading to applications of lasers for the initiation of propellants and propelling charges for large-caliber guns and the development of ignition systems and requirements for current and future propulsion systems. Dr. Forch was a NRC postdoctoral fellow at the BRL in 1985. His primary areas of research included the application of laser-based techniques such as multiphoton photochemistry, multiphoton fluorescence and ionization spectroscopy, and laser photochemistry to understand the detailed chemistry and energy-releasing processes of energetic materials. Dr. Forch received a B.S. in chemistry and an M.S. in physical chemistry from Illinois State University in 1978 and 1979, respectively. He received a Ph.D. in physical chemistry/chemical physics from Wayne State University, in Michigan, in 1984.

Scott E. Meyer is the managing director of the Maurice Zucrow Laboratories at Purdue University. He is responsible for the safe and productive utilization of Zucrow Labs' unique research and testing capabilities. He collaborates with faculty in the development of new experimental capabilities and is responsible for the design and implementation of new facility infrastructure. Mr. Meyer supervises Zucrow staff and approximately 75 graduate students in the design, fabrication, setup, and safe operation of gas turbine, rocket, and other combustion experiments, including the specification of instrumentation; data acquisition and control systems; and fluid systems and components. Prior to joining Zucrow Laboratories, Mr. Meyer was a propulsion engineer at Beal Aerospace and a project engineer in the Propulsion Wind Tunnel group at Arnold Engineering Development Center. Mr. Meyer received both a B.S. and an M.S. in aeronautics and astronautics engineering from Purdue University.

Bobby L. Wilson is the L. Lloyd Woods Distinguished Professor of Chemistry and Shell Oil Endowed Chaired Professor of Environmental Toxicology at Texas Southern University (TSU). He has held many positions during his more than 30 years at TSU, including provost and acting president. Dr. Wilson received his B.S. in chemistry from Alabama State University; an M.S. in chemistry from Southern University in Baton Rouge, Louisiana, and a Ph.D. in chemistry from Michigan State University.

Dr. Wilson's research has focused on unusual metal-centered complexes of early first, second, and third row transition elements using spectroscopic techniques and in the area of environmental chemistry and toxicology, particularly water and air pollution. In addition to water and air, trace metal and radionuclide concentrations are also being investigated. Other areas of concerns are catalytic coal liquefaction to enhance the conversion yields and properties of the liquid products from coal and the synthesis of transition metal complexes as models in an effort to reduce lunar materials, such as titanium ilmenite ($FeTiO_3$) and rutile (TiO_2) with the production of molecular oxygen. This could lead to the production of molecular oxygen on the moon.

As founder of the TSU-NASA Research Center for Biotechnology and Environmental Health (RCBEH) at TSU, Dr. Wilson led a team to investigate the toxicology of the space travel environment by using the cutting-edge tools, approaches, and applications of nanotechnology and genomics. The overall goals, associated with the two focus areas of microorganisms and genotoxicology, are to identify "space genes" that may affect human adaptation in the space environment and to measure oxidative stress and DNA damage in human and mammalian cells.

Dr. Wilson has been instrumental in building the research component of the science programs at TSU. His efforts have generated over $60 million in research and training grants to the university. His commitment to promoting the TSU's research agenda for its professors and producing future scientists led to the construction of the TSU Science Center, a $35 million structure with state-of-the-art laboratories, classrooms, and computer labs. A 4,300 square foot lab houses the Houston Louis Stokes Alliance for Minority Participation Program. This lab has 33 computers, two large printers, and two 50-inch plasma flat screen monitors. It also has teleconferencing capabilities, which enable students to interact with and present their research to other colleges and universities.

Perhaps his most ambitious and forward-looking venture has been the establishment of the Louis Stokes Alliance for Minority Participation (LSAMP) in seven Houston-area colleges and universities. He is the co-principal investigator of this consortium, which is designed to substantially increase the number of underrepresented minorities in the fields of science, technology, engineering, and mathematics. Its success at Texas Southern University and other Houston-area colleges and universities has been judged to be among the best LSAMP program in the nation. This judgment bears witness to Dr. Wilson's vision and leadership.

Dr. Wilson has also been a mentor to over 70 master's degree students in chemistry and 20 master's and/or Ph.D. students in the Environmental Toxicology Program, which he was instrumental in establishing as TSU's first Ph.D. program.