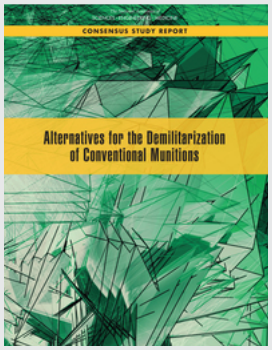

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Committee on Alternatives for the Demilitarization of Conventional Munitions

Board on Army Science and Technology

Division on Engineering and Physical Sciences

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Preface

I have been on a number of National Academies committees, all of which have been challenging. This committee has been different in many respects. First, it is congressionally mandated, which puts it on a higher level of visibility. That aside, the subject matter delves into an area that has been controversial for many years—from the perspective of the public, regulators, and the military. Open burning/open detonation (OB/OD) of excess, obsolete, or unserviceable munitions has been a common disposal practice for decades, even centuries. It is quick, relatively straightforward, and relatively inexpensive. Although there have been safety incidents, it can also be conducted safely. The downside, as can be deduced from the word "open" is that OB/OD releases contaminants into the environment. During my observations of OB/OD operations at many locations, thick plumes of smoke and particulates are quite visible during these operations. Public interest groups have been opposed to OB/OD operations for years.

Yet the U.S. Environmental Protection Agency (EPA) and the states have issued permits under the Resource Conservation and Recovery Act (RCRA) for a number of OB/OD operations, and several permits are still pending. In order for a facility to receive an RCRA permit, the operation must be shown to be protective of human health and the environment—a statutory requirement of RCRA. This would lead one to believe that OB/OD can be conducted in a manner that, according to environmental regulatory agencies, is protective of human health and the environment. The permits, however, are accompanied by many restrictions, all of which limit what can be treated, when it can be treated, how it can be treated, and the rate of treatment. They also contain extensive monitoring requirements. Many hazardous waste cleanup sites exist across the United States, and the contamination as a result of OB/OD operations is well documented. But most, if not all, of these are pre-RCRA "legacy sites" operated without the restrictions we see in RCRA permits today.

On the other hand, there are new and emerging technologies for the demilitarization of conventional munitions, which consist mostly of some type of contained burning (CB) or contained detonation (CD). Recycling and recovery are also employed, as are other technologies. These technologies, by their nature, limit the release of constituents into the environment to a relatively small amount. CB/CD technologies are more environmentally acceptable—RCRA permits for their operation carry fewer restrictions as compared to OB/OD. Like OB/OD, CB/CD can also be conducted safely, but there is an increased risk to workers due to additional handling requirements associated with many of the alternatives. Public interest groups will always favor CB/CD over OB/OD. The primary downside of most of the available CB/CD technologies is cost and throughput. And considering the huge inventory of munitions maintained by the military that is destined for destruction, cost and throughput become very important considerations, especially when you consider that EPA and the States maintain that permitted OB/OD operations are safe for human health and the environment.

I would like to thank the U.S. Army and the product director for demilitarization, Department of Defense representatives and staff, EPA and the state regulators, and Army contractors that provided input to the committee's deliberations and accommodated its numerous inquiries. I also want to thank the vendors of alternative technologies that addressed the committee and responded to its inquiries. My thanks also to representatives of the public interest groups that addressed the committee as well, including California Communities Against Toxics, the Cease Fire Campaign, and Environmental Patriots of the New River Valley, for offering their perspectives on the issues. I would also like to thank Senator Tammy Baldwin and her staff for their input and direction during the conduct of the study. I must also thank the staff of the National Academies of Sciences, Engineering, and Medicine for their tireless and outstanding support, especially Bruce Braun, Jim Myska, Greg Eyring, Nia Johnson, and Deanna Sparger. I also thank the committee members for putting up with my challenging schedule, onerous demands, and my dry and only sometimes witty sense of humor. Last, I must offer my very sincere thanks to Committee Vice Chair Doug Medville for his dedication, perseverance, and attention to detail. It was often hard to tell who was the chair and who was the vice chair. Thank you, Doug!

Todd A. Kimmell, *Chair*
Committee on Alternatives for the Demilitarization of Conventional Munitions

Acknowledgment of Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, 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 thank the following individuals for their review of this report:

Dianne Chong, NAE,[1] Boeing Research and Technology (retired),
Michael Ettenberg, NAE, Dolce Technologies,
David W. Graham, The Dow Chemical Company, (retired),
Thomas F. Hall, Jr., Independent Consultant,
David A. Hoecke, ES Thermal, Inc.,
John R. Howell, University of Texas, Austin,
Louis E. Martino, Argonne National Laboratory, and
Charles K. Westbrook, NAE, Lawrence Livermore National Laboratory (retired).

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by Hyla S. Napadensky, retired vice president, Napadensky Energetics, Inc. She was responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

[1] Member, National Academy of Engineering.

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Summary

As of the writing of this report, the U.S. military has a stockpile of approximately 400,000 tons of excess, obsolete, or unserviceable munitions. About 60,000 tons are added to the stockpile each year. Munitions include projectiles, bombs, rockets, landmines, and missiles. Open burning/open detonation (OB/OD) of these munitions has been a common disposal practice for decades, although it has decreased significantly since the 2011.

OB/OD is conducted at numerous installations across the United States, including Army, Air Force, and Navy/Marine bases as well as at munitions production sites, on military ranges, and at other locations, such as Department of Energy (DOE) laboratories. OB/OD is relatively quick, procedurally straightforward, and inexpensive. OB typically involves either the burning of bulk propellants and energetics and waste materials contaminated with these materials in burn pans or other structures, or the static firing of rocket and missile motors. Static fire involves securing the motors on stands and igniting them. OD typically involves placing munitions and donor charges into pits, covering them with earth and activating the donor charges. While there have been safety incidents, OB/OD is considered by the Army to be a generally safe technology for workers. The downside of OB and OD is that they release contaminants from the operation directly into the environment. During OB/OD operations, thick plumes of smoke are quite often visible during these operations. This has generated significant concern on the part of public interest groups.[1] These groups have been opposed to OB/OD operations for years, claiming the lack of adequate monitoring of emissions and potentially cumulative negative impacts on human health and the environment.

Current OB/OD operations are conducted under Resource Conservation and Recovery Act (RCRA) permits. These permits are built from a standard foundation of RCRA regulatory requirements, and are then customized for each facility. They include extensive conditions, including limitations on what can be treated, the rate of treatment, time-of-day and weather restrictions, and monitoring requirements. In order for a facility to receive an RCRA permit, the operation must be shown to be protective of human health and the environment—a statutory requirement of RCRA (42 U.S.C. 6902).

Over time, a number of technology alternatives to OB/OD have become available and more are in research and development. Alternative technologies generally involve some type of contained destruction of the energetic materials, including contained burning (CB) or contained detonation (CD) as well as contained methods that forego combustion or detonation. Emissions from CB and CD operations are captured, and gaseous emissions are treated in pollution abatement systems before release to the environment. Recycling, recovery, and reuse of munition components are often employed as well.

These alternative technologies, by their nature, release far fewer emissions into the environment, and thus are generally perceived by the public as more environmentally friendly and acceptable. There is the possibility of an increased safety risk to workers owing to additional handling requirements associated with preparing munitions for disposal by many of the alternative technologies, such as disassembly, size reduction, and the removal of problematic components such as cluster munitions. It should be noted, however, that some demilitarization facilities use automation to minimize handling and worker risk. This leads to the primary downside of most of the available CB/CD technologies. Alternative technologies are expected to have higher capital and operating costs than OB/OD because of the need to procure and install equipment, construct the facility, and pay for utilities, maintenance, and personnel. This cost differential would be even greater were automation used to minimize the handling of munitions. However, the closure and cleanup of alternative technology facilities will likely be less expensive than

[1] In the course of its work the committee engaged with representatives of the California Communities Against Toxics, the CeaseFire Campaign, the Center for Public and Environmental Oversight, and the Environmental Patriots of the New River Valley.

OB/OD, as continuing contamination of the surrounding environment during repeated OB/OD operations will require extensive mitigation during closure, particularly if groundwater is contaminated.

In general, many of the CB/CD technologies will also have lower throughput than OB/OD operations. This difference may not be as great as generally assumed, considering the ability of CB/CD facilities to operate at any hour of the day and in most weather conditions. However, throughput for OB/OD operations may be substantially increased by using more burn pans and detonation pits, so long as these can be accommodated within existing permit conditions. It has become clear that throughput is often munition and technology specific.

In response to concerns expressed by public interest groups, the U.S. Congress directed the Secretary of the Army to enter into an arrangement with the Board on Army Science and Technology of the National Academies of Sciences, Engineering, and Medicine to conduct an evaluation of alternative technologies for the demilitarization of conventional munitions in lieu of OB/OD. Specifically, Section 1421 of the National Defense Authorization Act for Fiscal Year 2017 included the following statement of task (SOT) for the study:

- A review of the current conventional munitions demilitarization stockpile, including types of munitions and types of materials contaminated with propellants or energetics, and the disposal technologies used.
- An analysis of disposal, treatment, and reuse technologies, including technologies currently used by the Department and emerging technologies used or being developed by private or other governmental agencies, including a comparison of cost, throughput capacity, personnel safety, and environmental impacts.
- An identification of munitions types for which alternatives to open burning, open detonation, or non-closed loop incineration/combustion are not used.
- An identification and evaluation of any barriers to full-scale deployment of alternatives to open burning, open detonation, or non-closed loop incineration/combustion, and recommendations to overcome such barriers.
- An evaluation of whether the maturation and deployment of governmental or private technologies currently in research and development would enhance the conventional munitions demilitarization capabilities of the Department.

The SOT lays out both the nature of and the constraints of the committee's work. While the committee must address each item of the SOT, it is not permitted to exceed the scope of its work as set forth in the SOT. The SOT specifically focuses on the Department of Defense (DoD) conventional munitions demilitarization stockpile being destroyed at seven stockpile depots: Anniston Munitions Center; Blue Grass Army Depot (BGAD); Crane Army Ammunition Activity (CAAA); Hawthorne Army Depot; Letterkenny Munitions Center (LEMC); McAlester Army Ammunition Plant (MCAAP); and Tooele Army Depot (TEAD). It also includes private sector "industry partners" that operate under contract to the DoD to demilitarize stockpile munitions at their facilities using alternative technologies. It does not include OB/OD at other military bases, ammunition plants, military ranges, or other government-owned locations where OB/OD is conducted.

Nevertheless, the committee understands and acknowledges that the concerns of the public that resulted in this study extend beyond the demilitarization stockpile. The SOT was focused on the conventional demilitarization stockpile and, thus, prevented the committee from specifically addressing other OB/OD locations (discussed in Chapter 1). The committee's work, however, does reflect the concerns of public interest groups, and the committee's findings and recommendations for this study will have implications for, and applicability to, OB/OD conducted at these other locations.

MAIN MESSAGES

The body of this report includes 30 findings and 8 recommendations that address a number of topics in some detail. The committee has consolidated the results of its work into the following six main messages. The findings and recommendations are listed below.

1. The Office of the Product Director for Demilitarization (PD Demil) has a stated strategic goal to increase the use of alternative technologies in lieu of OB/OD. The Army has made progress in implementing alternatives at many of the stockpile and contractor locations.
2. Some shock-sensitive or unstable munitions may not be safe to handle or transport for treatment by alternative technologies; thus, the capability for OB/OD will always be needed.
3. Viable alternative technologies exist within the demilitarization enterprise, either stand-alone or as part of a treatment train, for almost all munitions currently being treated within the DoD conventional munitions demilitarization stockpile via OB/OD.
4. Alternative technologies have both pros and cons. Implementing alternative treatment technologies for munitions that are currently treated via OB/OD will result in reduced emissions but will be associated with increased capital and operating costs, although with lower closure costs. The alternative technologies treating the same munitions as OB/OD will have varying throughput capacities compared to OB/OD, depending on the capabilities of the technologies, munitions being treated, and other factors, including

permit restrictions (e.g., net explosive weight limits and weather restrictions).

5. Public interest groups are expected to generally favor alternative technologies over OB/OD. Further progress in implementing alternatives will be facilitated by proactive engagement with federal and state regulators and the affected public, featuring increased two-way communication and transparency in decision making.
6. There is only one barrier to the full-scale deployment of alternative technologies in lieu of OB/OD—namely, funding. In addition, there are two other considerations that could significantly impact the transition away from OB/OD: (1) The PD Demil's lack of a detailed implementation plan to institutionalize the 2018 Demilitarization Strategic Plan and (2) the potential for public opposition to specific alternative technologies at the individual stockpile depots.

FINDINGS AND RECOMMENDATIONS

Finding 2-1. According to PD Demil, the primary factor determining the quantity of munitions demilitarized in a given year is the budget, not technological capacity or availability.

Finding 2-2. Despite the Army's stated strategic goal of replacing OB/OD with alternative contained treatment technologies, reducing the use of OB/OD is not an explicit criterion used to evaluate projects in PD Demil's research, development, testing, and evaluation program.

Recommendation 2-1. The Army should include the potential to reduce the use of open burning and open detonation as a criterion used to evaluate candidate projects in Office of the Product Director for Demilitarization's research, development, test, and evaluation program.

Finding 2-3. The Army demilitarization program appears to have instituted an effective safety management program.

Finding 2-4. According to data provided to the committee by PD Demil, the use of OB/OD as demilitarization treatment methods has declined from an estimated 80 percent of demilitarized munitions in the mid-1980s to an average of about 30 percent in recent years.

Finding 2-5. Nonmunitions waste materials, including solvents and other organic liquids, positively identified as pyrotechnic, explosive, or propellant-contaminated are treated via OB at some of the stockpile demilitarization sites.

Recommendation 2-2. The Office of the Product Director for Demilitarization should investigate the use of alternative treatment or disposal methods, including commercial treatment, storage, and disposal facilities, for positively identified pyrotechnic, explosive, or propellant-contaminated nonmunitions wastes.

Finding 4-1. Contained burn chambers with associated pollution abatement systems designed to treat propellants and other energetics are available commercially and can be designed to meet the needs of PD Demil stockpile demilitarization as a substitute for OB.

Finding 4-2. Contained detonation chambers that can demilitarize some conventional munitions and munition components exist; however, limited explosion containment capabilities and the need to prepare or preprocess munitions can limit the applicability of these chambers.

Finding 4-3. For some munitions, combinations of processing steps will be required to prepare munitions for treatment in a CB or CD chamber. Although this increases complexity and handling risks, if not conducted remotely using automated equipment, these steps enable the munitions to be demilitarized without using OB or OD.

Finding 4-4. Several of the emerging technologies are in early stages of research and development and have not been demonstrated under full-scale operating conditions. None of those examined by the committee is expected to make a significant contribution to demilitarizing munitions in the near future.

Finding 6-1. There is no formal Environmental Protection Agency guidance for permit applicants or authorized state agencies to determine the requirements for applications or permit conditions (e.g., risk goals, treatment efficiencies, or waste and operational limitations) for alternative technology units that would be permitted as Subpart X units.

Finding 6-2. Provisions contained in permits for existing alternative technologies at Army demilitarization depots may limit the types of waste munitions that can be treated or the throughput of the units. Some of these limitations are based on the technology or regulatory limitations, but some may be the result of (1) how the RCRA application was worded or (2) availability of RCRA waste characterizations for a variety of munitions.

Finding 6-3. Public interest group representatives express the need to consider community preferences and site-specific conditions when selecting an alternative technology to implement, install, and permit at any of the seven demilitarization depots.

Recommendation 6-1. The Army should investigate whether permits for existing alternative technology units at

Army munition demilitarization depots can be amended to be more flexible regarding the types, frequency, and amounts of munitions that can be treated.

Recommendation 6-2. The Army should identify issues that could affect the Resource Conservation and Recovery Act permitting process for alternative technologies, including public concerns, and work with regulators in the states with jurisdiction over the seven demilitarization depots to establish requirements for Subpart X applications (e.g., developing scientific and technical analysis documents, emission modeling and estimates, and efficiency documentation for similar units) so as to address issues and questions before they become a problem that could significantly delay permitting alternative technologies.

Finding 7-1. Alternatives to OB/OD are not being used for some munitions because the munitions have become unstable and are too hazardous for the handling and transportation required for demilitarization using alternative technologies. A determination by the PD Demil that a munition is unstable and potentially shock sensitive is a valid reason for performing demilitarization via OB/OD to minimize transportation and handling and, therefore, the exposure of technicians to the explosive hazard. The capability for OB/OD will always be needed.

Finding 7-2. The configuration of some munitions will require handling and processing steps prior to munitions demilitarization using alternative technologies. This adds complexity to the process, may increase the cost of demilitarization, and may increase risks to workers. These factors will have to be considered when evaluating the use of alternative technologies.

Finding 7-3. The organic capabilities of the PD Demil and the contractor community have the technical capability—or could develop the capability—to demilitarize nearly all of the munitions in the stockpile using alternative technologies. There will, however, always be some munitions that need to be treated by OB/OD for safety reasons.

Recommendation 7-1. In keeping with stated strategic goal to increase the use of contained disposal, resource recovery, and recycling consistent with continuing to ensure minimal exposure of personnel to explosive safety risks, the Office of the Product Director for Demilitarization should perform a detailed technical and engineering evaluation of the munitions in the inventory currently demilitarized by open burning or open detonation and evaluate appropriate alternative demilitarization technologies for each munition along with an implementation schedule and budget requirements. This detailed evaluation should include the option of shipping munitions and munitions components to other organic or contractor facilities for demilitarization.

Finding 8-1. Each of the alternative technologies that the committee evaluated as potential replacements for OB and OD would have lower emissions and less of an environmental and public health impact, would be monitorable, and would likely be more acceptable to the public.

Finding 8-2. Throughput capacity for OB/OD and alternative technologies is dependent on many factors, some of which may offset each other. These factors include the capability of the treatment technology, the characteristics of the munition or munition component being treated, and permit restrictions.

Finding 8-3. Most of the alternative technologies that could replace OB/OD are mature and many have already been permitted.

Finding 8-4. The alternative technologies that could replace OB/OD could pose either more or less risk to personnel depending on the munition and on the extent to which munitions handling is required. The safety approvals currently required by the Department of Defense Explosives Safety Board for both OB/OD and CB and CD and their associated demilitarization processes are adequate to minimize explosive accidents and injuries.

Finding 8-5. Hold-test-release capability is neither necessary nor appropriate for technologies treating conventional munitions and associated wastes because of the difference in acute toxicity between chemical warfare agents and the components of conventional munitions.

Finding 8-6. The committee requested but was unable to obtain sufficient data to draw general conclusions regarding the relative life cycle costs of OB and OD and the alternative technologies, although the capital (startup) costs of the alternatives will likely be higher while the costs of environmental monitoring and closure will likely be lower. Operating costs of the alternatives appear to vary widely and in some cases may be competitive with OB/OD.

Finding 9-1. There are no significant technical, safety, or regulatory barriers to the full-scale deployment of alternative technologies for the demilitarization of the vast majority of the conventional waste munitions, bulk energetics, and associated wastes.

Finding 9-2. The implementation and use of alternative technologies is a function of how much funding is requested by the Army and how much funding is appropriated, however, both the DoD and the Army have placed a relatively low priority on funding the demilitarization program, including the implementation of additional alternative technologies to replace OB/OD, as reflected in their past budget requests.

Finding 9-3. Uncertainty in the current and future funding levels for demilitarization of conventional munitions is a barrier to the development and increased use of alternatives to OB/OD.

Finding 9-4. Absent a clear directive from Congress, accompanied by sufficient funding, it will not be possible for the Army to implement full-scale deployment of alternative technologies in lieu of OB/OD.

Recommendation 9-1. To enable the Department of Defense and Congress to decide what level of resources should be devoted to increasing the use of alternative technologies in lieu of open burning (OB) and open detonation (OD), the Office of the Product Director for Demilitarization should prepare an analysis of the full life cycle costs of demilitarization of the munitions in the stockpile using alternative technologies and OB/OD to determine the funding necessary to increase the use of alternative technologies over various periods of time and the impact of that increase on the demilitarization enterprise.

Finding 9-5. The goals and metrics in the 2018 Demilitarization Strategic Plan are focused on determining whether the program is meeting or exceeding its planned reduction in OB/OD and increase in Reclamation, Recycling, and Reuse, but they do not set quantitative end points or time tables.

Finding 9-6. PD Demil's stated goal is to increase the use of contained disposal technologies. In addition, the Environmental Protection Agency staff and state staff presentations to the committee indicated an evolving preference to move away from OB/OD. Public interest groups also support the adoption of alternative technologies.

Finding 9-7. PD Demil has no implementation plan or process for increasing the use of alternative technologies and transitioning away from OB/OD.

Recommendation 9-2. The Office of the Product Director for Demilitarization should develop a detailed implementation plan for transitioning from open burning and open detonation to alternative technologies, with appropriate performance metrics, and institutionalize it throughout the Demilitarization Enterprise.

Finding 9-8. There is a potential that proposals for alternative technologies to replace OB/OD at the stockpile sites could be contested by the public.

Finding 9-9. The public's acceptance of technologies that they view as being risky may be fostered if the Army adopts more effective public involvement activities. Without proactive attention by PD Demil to the ways that the perception of technology and management are intertwined, public support may be undermined, resulting in delays in full-scale deployment of alternative technologies to replace OB/OD.

Recommendation 9-3. The Office of the Product Director for Demilitarization should, in coordination with the Joint Munitions Command Public and Congressional Affairs Office, include in its implementation plans proactive public affairs activities that build on the experience of other successful programs in resolving public concerns.

1

Introduction

In Section 1421 of the National Defense Authorization Act for Fiscal Year 2017, the U.S. Congress directed the Department of Defense (DoD) to enter into an arrangement with the Board on Army Science and Technology of the National Academies of Sciences, Engineering, and Medicine to conduct a study of the DoD conventional munitions demilitarization program. The study can be summarized as an evaluation of alternative technologies for the destruction of conventional munitions in lieu of open burning (OB) or open detonation (OD). The statement of task (SOT) is shown in Box 1-1.

The SOT specifically focuses on the DoD conventional munitions demilitarization stockpile.[1] The Army sponsor for this study, the Office of the Product Director for Demilitarization (PD Demil), defines this as the munitions stockpile currently being stored and destroyed at seven Army stockpile depots,[2] referred to by the Army as "organic capabilities."[3] The SOT also includes private sector "industry partners" that operate under contract to DoD at various sites across the United States. According to the PD Demil, these industry partners are part of the Demilitarization Enterprise; they are used to increase capacity beyond what the seven Army stockpile depots can execute.

The SOT not only reflects the directive of Congress, but also establishes the basis for the National Academies

BOX 1.1
Statement of Task

Section 1421 of the National Defense Authorization Act for Fiscal Year 2017 included the following statement of task for the study:

- A review of the current conventional munitions demilitarization stockpile, including types of munitions and types of materials contaminated with propellants or energetics, and the disposal technologies used.
- An analysis of disposal, treatment, and reuse technologies, including technologies currently used by the Department and emerging technologies used or being developed by private or other governmental agencies, including a comparison of cost, throughput capacity, personnel safety, and environmental impacts.
- An identification of munitions types for which alternatives to open burning, open detonation, or non-closed loop incineration/combustion are not used.
- An identification and evaluation of any barriers to full-scale deployment of alternatives to open burning, open detonation, or non-closed loop incineration/combustion, and recommendations to overcome such barriers.
- An evaluation of whether the maturation and deployment of governmental or private technologies currently in research and development would enhance the conventional munitions demilitarization capabilities of the Department.

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[1] Conventional ammunition awaiting demilitarization and disposal stockpile. The total demilitarization stockpile as of September 30, 2017, consisted of 430,987 tons of munitions, with 28,153 tons consisting of rockets and missiles and 402,834 tons consisting of conventional munitions. J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee, October 23, 2017.

[2] The seven DoD stockpile depots are Anniston Munitions Center; Blue Grass Army Depot (BGAD); Crane Army Ammunition Activity (CAAA); Hawthorne Army Depot; Letterkenny Munitions Center (LEMC); McAlester Army Ammunition Plant (MCA); and Tooele Army Depot (TEAD).

[3] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

contractual requirements for the study. The committee is not permitted to exceed the scope of its work as set forth in the SOT. Hence, the committee investigation and analysis is focused on the five tasks set forth in the SOT and on the current conventional munitions demilitarization stockpile.[4]

The words energetic compounds (or energetic materials), explosives, and propellants are used throughout this report. Energetic materials store chemical energy for later release. It is a very broad term that encompasses all the chemical components of military munitions that cause the munition to function as designed. Energetic compounds can include explosives such as RDX, TNT, and/or lead azide and lead styphnate used in warheads; propellants used in rockets and missiles; and pyrotechnics used for such things as decoy flares or illumination.

OVERVIEW OF THE CONVENTIONAL DEMILITARIZATION ENTERPRISE

The DoD designates the Army as the Single Manager for Conventional Ammunition, with the following mission:[5]

> Perform life-cycle management for demilitarization of conventional ammunition for the Department of Defense.

Demilitarization Enterprise strategic goals for PD Demil are as follows:[6]

- Efficiently reduce the demilitarization stockpile by maximizing use of the capacity of the organic and commercial industrial base;
- Continuously improve the efficiency and effectiveness of demilitarization capabilities within the enterprise;
- Implement design for demilitarization for all new and modified conventional ammunition products; and
- Increase the use of contained (“closed”) disposal, resource recovery, and recycling consistent with continuing to ensure minimal exposure of personnel to explosive safety risks.

Additional information about the Army’s organizational structure that oversees conventional munitions demilitarization, the seven DoD stockpile sites, and the makeup of the demilitarization stockpile is presented in Chapter 2.

OVERVIEW OF DEMILITARIZATION TECHNOLOGIES

OB/OD of munitions has been a common demilitarization technology for decades. OB conducted for munitions in the stockpile at the stockpile sites consists mainly of spreading out propellants in an open-top metal burn pan located in an open area, followed by ignition and burning. OD conducted for munitions in the stockpile at the stockpile sites consists mainly of placement of munitions in an outside pit, covering with adjacent soil, followed by detonation. Static firing of rockets and missiles in the stockpile at the stockpile sites is typically conducted by securing the rocket or missile in a stand outside, followed by ignition and burning. The committee considers static firing of rocket and missile motors to be another type of OB.

OB/OD operations are technically simple and relatively straightforward. They are relatively inexpensive to conduct as compared to many of the alternatives (GAO, 2015). All seven Army demilitarization depots currently have permitted OB/OD facilities. While there have been safety incidents, OB/OD technologies are consistent with the Demilitarization Enterprise stated strategic goal of ensuring minimal exposure of personnel to explosive safety risk.

One of the primary downsides of OB/OD operations is that, by definition, specifically referring to the word “open,” by-products of the burning or detonation are released directly into the environment—plumes of smoke and particulate matter are often quite visible during and following OB/OD operations. OB/OD also often results in noise, shock waves, and ground tremors. Energetic compounds are commonly ejected and other contaminants, including heavy metals, are commonly released to the surrounding media (air, soil, water) during OB/OD events.

OB/OD permits have been issued for 53 locations; 7 additional locations are in interim status, with permits pending.[7] The DoD holds 35 of these permits. Permits for hazardous waste facilities, including OB/OD operations, are issued by the U.S. Environmental Protection Agency (EPA) or authorized states under the Resource Conservation and Recovery Act (RCRA). OB/OD RCRA permits are developed in accordance with RCRA’s Miscellaneous Unit requirements (40 CFR 264 Subpart X). According to EPA, RCRA permits for OB/OD operations, as well as for alternative technologies that fall under Subpart X, are built from a standard foundation of RCRA regulatory requirements, and then customized for each facility.[8] In order for a facility to receive an RCRA permit, the operation must be protective of human health and the environment—a statutory requirement of RCRA.

Alternative technologies currently in use that are comparable to OB/OD may be characterized as contained burning (CB) or contained detonation (CD). DoD also employs a

[4] The munitions in the demilitarization stockpile comprise only a subset of materiel currently treated by OB/OD at a variety of military installations including ammunition production plants and practice ranges. While the alternative treatment technologies discussed in this study will have application for some of the materiel treated by OB/OD at these installations, this materiel is not considered part of the demilitarization stockpile and therefore operations at these sites are not discussed in this study.

[5] J. McFassel, product director for demilitarization, PEO AMMO, “Demilitarization Overview for National Academy of Sciences,” presentation to the committee, August 22, 2017.

[6] Ibid.

[7] K. Shuster, engineer, senior technical expert, U.S. EPA, “Alternatives for the Demilitarization of Conventional Munitions,” presentation to the committee on August 22, 2017.

[8] Ibid.

number of preparatory or pretreatment technologies (prior to CB/CD) and resource recovery or recycling technologies for various categories of munitions in the stockpile. Still other alternative technologies being investigated by the Army are in various stages of research and development, testing, and evaluation.[9]

The use of alternative technologies must also meet regulatory requirements under RCRA. As with OB/OD, in order to receive an RCRA permit, alternative technologies must be protective of human health and the environment. Depending on the technology, some alternatives may be permitted as incineration or combustion units. Many alternatives would be permitted under RCRA Subpart X—just as for OB/OD operations. Because most of the alternatives entail some sort of CB or CD and have back-end treatment for combustion and detonation by-products, by their nature, these technologies limit the release of particulates and hazardous constituents into the environment to a relatively small amount.

With the possible exception of alternative technologies that are considered to be incineration technologies, alternative technologies are generally viewed more favorably by public interest groups. Incineration technologies have historically been opposed by public interest groups, although they would offer far greater control over emissions from munition demilitarization operations than would OB/OD. These technologies must also be permitted under RCRA (40 CFR 264 Subpart O) and employ back-end pollution abatement systems prior to release of air emissions to the atmosphere.

The downside of many of the CB/CD technologies is that they are typically more expensive to construct and systemize than OB/OD, although closure activities under RCRA will typically be less expensive for alternative technologies as compared to OB and OD. The rate of treatment for alternative technologies, referred to as throughput, may also be lower for alternative technologies because of technological limitations (e.g., net explosive weight limitation, size of the chamber) and operational limitations (e.g., time needed to prepare munitions, cool-down periods). Additional units may be added to increase throughput, if allowed by permit. OB/OD operations have throughput limitations as well, although use of multiple burn pans or detonation pits, if allowed by the permit, could be used to increase throughput for OB/OD operations. OB/OD operations, however, must comply with specific weather conditions and time-of-day constraints under the permit, which limits throughput. Alternative technologies can operate continually and without most of the restrictions related to daylight or weather, though restrictions such as pausing operations when lightning is in the area will likely remain in effect. It is clear that the determination of throughput is technology and munition-specific. Regardless, considering the rather large size of the demilitarization stockpile and the current demilitarization budget (see Chapter 2), cost and throughput become important considerations.

OB and OD practices are described in Chapter 3. Alternative technologies are described in Chapter 4. Throughput and cost are discussed in each of these chapters.

TRANSITION FROM OB/OD TO CB/CD

The last Demilitarization Enterprise stated strategic goal listed above is to "Increase the use of contained ('closed') disposal,[10] resource recovery, and recycling consistent with continuing to ensure minimal exposure of personnel to explosive safety risks." This goal is particularly pertinent to this study. There appears to be a concerted and long-standing effort on the part of Congress and the Army to investigate and use alternatives in lieu of OB/OD.

The 106th Congress, House of Representatives Report 106-754 (to Accompany H.R. 4576), in its Appropriations Bill for the Fiscal Year ending September 30, 2001 (July 17, 2000), included the following statement:

> OPEN BURN/OPEN DISPOSAL PRACTICES
> The conferees are aware of public concern regarding possible health risks to civilian populations associated with the open burning/open detonation (OB/OD) of munitions and equipment at Army depots at various locations in the U.S. Most of these risks are believed to be associated with airborne gases, particles, and other contaminants carried downwind of the burn/detonation sites. The Army is directed to study potential alternative closed disposal technologies that do not release into the atmosphere and to report to Congress no later than September 30, 2001, on the possibility of phasing out OB/OD in favor of closed disposal methods. The report should include a review of technologies currently in existence and under development and assess the cost and feasibility of constructing facilities employing those technologies.

According to DoD's Joint Demilitarization Technology Report to Congress (DoD, 2000):

> The Fiscal Year 1999 funding included an additional $3.0 million to investigate and develop safe, efficient, and environmentally compliant technologies as alternatives to open burning/open detonation (OB/OD) to reduce the munitions demilitarization stockpile.

According to the 2007-2012 Demilitarization Strategic Plan (DoD, 2006), under the general category 3.2.8 Strategic Goal, Safety and Environmental Stewardship, Goal 3.2.8.1.5 is as follows:

[9] J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee on August 22, 2017.

[10] The committee is using the termed "contained" versus "closed" for two reasons. First, because most CB/CD systems eventually release an air stream to the environment, these systems are not truly closed. Second, the committee wants to clearly differentiate the type of treatment (open versus contained) from RCRA unit closure requirements.

> Limit open burn/open detonation (OB/OD) to 20% of execution to reduce its environmental impact.

In accordance with this goal, DoD presented information to the committee indicating that the Army has already significantly reduced use of OB/OD in favor of CB/CD.[11] The Army estimated that the use of OB/OD as demilitarization treatment methods has declined from an estimated 80 percent of demilitarized munitions in the mid-1980s to an average of about 30 percent in recent years as calculated by the committee (see Chapter 2).[12] This reduction appears to be due to a combination of factors, including placement of some classes of munitions back into serviceable accounts, increased use of resource recovery and recycling, and transitioning to CB/CD technologies.

The committee received a new demilitarization strategic plan in late May 2018, just as the committee was in the process of developing its first complete draft of the report. Titled "Strategic Plan for the Demilitarization Enterprise,"[13] it is described further in Chapter 2, and Chapter 9 addresses specific elements of the new strategic plan in Chapter 9 as well.

THE COMMITTEE'S APPROACH

There are a number of closed OB and OD sites that are currently being cleaned up under various environmental programs. EPA shows 54 closed OB/OD facilities as subject to cleanup.[14] Some of these closed OB/OD facilities are owned by entities other than the Army. However, most of these units were closed prior to obtaining RCRA operating permits. The committee refers to these as "legacy" units or operations.

Contamination from legacy OB/OD operations may be very different from contamination noted at permitted units, as legacy units were not subject to the same types of controls and conditions as exist for permitted units. One example is the present-day use of burn pans for OB. These came into use as a result of RCRA permit requirements. Prior to RCRA, OB was done directly on the ground surface (EPA, 2002). Similarly for OD, some of the controls used and conditions imposed now did not exist prior to RCRA. An example would be diversion of surface water runoff at permitted OB/OD sites to retention ponds (EPA, 2002). There are other examples as well of RCRA permit requirements for OB/OD units that would have the effect of limiting impacts to human health and the environment.

In addition, many of the legacy units or operations undergoing cleanup are complicated by contamination from adjacent operations or processes. Some, for example, were located adjacent to munitions production sites that released the same types of constituents as are typically associated with OB/OD sites.[15] In these cases, it is difficult to discern whether the source of the contamination at legacy sites was from the OB/OD operation, from adjacent operations or processes, or more likely, a combination of both.

The implication for this study is that the cleanup of legacy sites has no bearing on the comparison of existing RCRA permitted OB/OD units with alternative technologies. These legacy operations may have shaped public perception of OB/OD, but present-day OB/OD operations are conducted under an RCRA permit that federal and state regulators have found to be protective of human health and the environment. Therefore, the comparison of alternative technologies to OB/OD operations that the committee is charged with addresses only those Army operations that are permitted or seeking permits (interim status) under RCRA.

Another facet of this study that affects the scope of the committee's work pertains to the demilitarization stockpile. Only a portion of these munitions are currently treated via either OB or OD. Due to RCRA permit conditions or safety concerns, many types of munitions are presently not treated using OB/OD units. For example, permits for OB/OD units prohibit treatment of chemical warfare agents, munitions containing depleted uranium, and non-mass detonating explosives. Munitions that are not treated at the stockpile locations using OB/OD are not the focus of this study.

Also worth mentioning, there are a number of OB/OD operations at facilities across the United States that do not treat munitions in the stockpile. These include units "operated" by other military services (Air Force, Navy/Marines), the Department of Energy (DOE) and some of its National Laboratories, the National Aeronautics and Space Administration (NASA), and the private sector. They also include OB/OD operations at ammunition plants and operations on military ranges. There are also munitions demilitarization projects being performed on formerly used training ranges at closed and active military facilities. Demilitarization of munitions during these operations is also not evaluated. While this study will have implications for these other OB/OD operations, in accordance with the SOT, this study does not address them. Evaluation of applicability of the findings and recommendations laid out in this report to these other OB/OD operations may be helpful, however.

The SOT specifically calls out evaluation of "non-closed loop incineration/combustion." "Non-closed loop" is not commonly used to describe incineration or combustion technologies. CB/CD technologies permitted today involve treatment of the gaseous phase that results from incineration or combustion, typically in an engineered pollution abatement

[11] J.C. King, director for Munitions and Chemical Matters, HQDA, ODASA(ESOH), "DoD Open Burn and Open Detonation (OB/OD)," presentation to the committee on August 22, 2017.

[12] Ibid.

[13] "Strategic Plan: For the Demilitarization Enterprise," draft document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 25, 2018.

[14] K. Shuster, engineer, senior technical expert, U.S. EPA, "Alternatives for the Demilitarization of Conventional Munitions," presentation to the committee on August 22, 2017.

[15] Ibid.

system that achieves established emission/contaminant limits set by RCRA or the Clean Air Act, before being released to the atmosphere. In this sense, all modern permitted incineration or combustion processes are non-closed (open) loop in that they release treated gases to the environment. Technically, at this time there are no true closed loop incineration or combustion systems used for demilitarization of conventional munitions. Some alternative technologies do have the ability to hold and test emissions, and if appropriate, re-treat them, prior to release to the environment. These types of technologies are usually reserved for the treatment of chemical weapons, where the toxicity of and potential exposure to the chemical agent is of primary concern.

Considering that the SOT is focused on alternatives to OB and OD, the committee has specifically avoided comparing and contrasting "like technologies" against each other. For example, there are several types of technologies used for CB or CD. The Static Detonation Chamber (SDC) and the Controlled Detonation Chamber (CDC) may both be used to treat munitions in a contained system. In this report, these technologies are contrasted against OB/OD, but they are not purposely contrasted against each other.

Also important, while the SOT is clearly focused on evaluation of alternative technologies, the baseline is OB and OD. In the committee's comparisons, alternatives are evaluated against OB/OD as a baseline. For each type of alternative technology, the committee evaluated cost, throughput capacity, personnel safety, and environmental impacts, as required by the SOT. To ensure a thorough comparison of OB and OD to alternative technologies, the committee added a number of other criteria to its comparison. The full set of evaluation criteria employed in the comparisons are presented in Chapter 5.

The SOT requires evaluation of alternative technologies and whether there are barriers to full-scale deployment of alternatives to OB/OD. The committee makes no judgment as to when or whether OB/OD technologies should be replaced with alternative technologies.

The committee also decided to limit its assessment to technologies being used or researched within the United States. The committee did not research technologies being used or developed internationally unless they were already being used, permitted, or researched within the United States. Information on alternative technologies used or researched in the United States were reviewed, however, even if they are not currently used on munitions maintained within the demilitarization stockpile at the seven stockpile sites. These technologies are also addressed in Chapter 4.

THE IMPORTANCE OF CONSIDERING REGULATORY POLICY, HEALTH AND SAFETY CONCERNS, AND PUBLIC CONFIDENCE

As indicated above, OB/OD and most alternative technologies used to treat waste conventional munitions require operating permits issued by EPA or authorized states. The primary regulatory authority is regulations issued pursuant to RCRA, mentioned previously, but the Clean Air Act also applies in some cases. Under RCRA, OB of hazardous waste is prohibited except for the OB and detonation of waste explosives. Waste explosives include waste that has the potential to detonate and bulk military propellants that cannot be safely disposed through other modes of treatment (40 CFR 265.382). EPA allowed OB/OD for waste explosives and propellants at the time of the initial promulgation of the RCRA regulations, recognizing that safe alternatives to OB/OD were not available at the time (45 FR 32655, May 19, 1980). Subsequently, OB/OD units have received RCRA operating permits under Subpart X as miscellaneous units. The committee accepts that permits issued for OB and OD and alternative technologies meet the RCRA statutory requirement to ensure protection of human health and the environment.

EPA has no current regulation or policy that prohibits or limits the issuance of RCRA permits for OB/OD facilities or that promotes alternative technologies.[16] Similarly, two authorized state environmental agencies with jurisdiction over Army stockpile OB/OD facilities stated that there is no current regulation or official policy that prohibits or limits the issuance of RCRA permits for OB/OD facilities or that promotes the use of alternative technologies in lieu of OB/OD.[17] The EPA staff presentation to the committee included a recently initiated project to identify alternatives to OB/OD.[18] It was noted that the Draft Open Burning/Open Detonation Permitting Guidelines issued in EPA Region 3 (February 2002) indicates that the permit applicant should include a justification of the need for OB/OD, including the evaluation of alternative technologies. However, these guidelines were never made final, and, as with all regional guidance, are nonbinding on authorized state regulatory agencies or other regions.

Human health and safety concerns are of paramount importance in operating any demilitarization operation. While OB and OD both entail personnel safety risks, many alternatives to OB and OD involve additional handling of munitions, which could present an increased personnel safety risk. Safety in the handling, transportation, and destruction of stockpile munitions is imperative, and OB/OD and alternatives must meet established explosive and safety criteria for personnel and the public. Because of this, the Department

[16] Response to information request submitted by the committee, documents provided via e-mail on October 20, 2017, by K. Shuster, engineer, senior technical expert, U.S. EPA.

[17] L. Houseal, Pennsylvania Department of Environmental Protection, "Pennsylvania Regulatory Perspectives," presentation to the committee, December 11, 2017. S. Cobb, chief, Land Division, Alabama Department of Environmental Management, "Alabama Regulatory Perspectives," presentation to the committee, December 11, 2017.

[18] Response to information request submitted by the committee, documents provided via e-mail on October 20, 2017, by K. Shuster, engineer, senior technical expert, U.S. EPA.

of Defense Explosives Safety Board (DDESB) has a crucial role in ensuring adequate protective measures for workers and the surrounding area.[19] Because DDESB reviews and approves all OB/OD and alternative technology operations, the committee accepts that OB/OD and alternative technologies have been determined to meet personnel safety requirements.

This study also addresses public confidence in alternative technologies and management of associated risks. It is well understood that social preferences and perceptions of technologies and how risks are managed can impact the design and implementation of technologies. Thus, the committee includes public confidence as one of the important evaluation criteria for OB/OD and alternative technologies. Public opposition to OB/OD and alternative technologies because of how risks are perceived and weighed and public confidence in management of risks has the potential to affect permitting timelines and thus the ability of PD Demil to achieve its stated strategic goals.

The committee notes that the language in the 2017 National Defense Authorization Act that required this study came about because of continuing concerns about the human health and environmental impacts of OB/OD that have been expressed by public interest groups. Public opposition to OB/OD has occurred primarily around other facilities (other than the seven addressed in this report) that treat waste munitions and also materials and wastes associated with conventional munitions, including dunnage, production wastes, supplemental fuels, buildings and construction materials, and contaminated solvents. Public interest groups have raised objections because of concerns they have about potential adverse impacts to public health and the environment, even though the activities have been permitted in accordance with RCRA standards.[20] These include contamination to surface and groundwater, soil, and air that may give rise to health risks, especially for vulnerable populations and those living close to the site. Public interest groups believe that emissions are inadequately monitored and that information is poorly shared with the public by the Army and regulatory agencies. They have also cited nuisance risks that residents in nearby communities have experienced from OB/OD, including property damage from vibration and blasts (e.g., broken windows, and broken dishes), noise, odors, and dust.

Regulatory issues are evaluated in Chapter 6. Chapters 7 and 8 contain the comparisons and evaluations required by the SOT. Chapter 9 addresses barriers and other considerations that might have an impact on the full-scale deployment of alternative technologies. The concerns presented to the committee by public interest groups are discussed in greater detail in Appendix D.

A WORD ABOUT COST

One of the four criteria specified in the SOT is cost. Cost information associated with the alternative technologies was not always available. The committee found that cost information was often considered proprietary. In other cases, cost information, although requested, was not always provided. In addition, where cost data were available to the committee, this information was often presented in qualitative terms or in a manner that was not conducive to direct comparisons among technologies. Determining startup and operating costs for technologies that may not be fully developed or operational may also be speculative. Hence, the committee's consideration of cost was in general, qualitative terms.

A related cost issue pertains to life cycle costs, which includes the cost of unit closure and associated cleanup. The cost of closing and cleanup of OB/OD sites can be substantial, particularly if groundwater is contaminated. While there are limited cleanup cost data on legacy sites, these cost data have limited applicability to the comparison of existing RCRA permitted OB/OD units with cleanup costs of alternative technologies. Alternative technologies' cleanup costs would normally be associated only with nonenvironmental media (e.g., equipment and buildings), since under current RCRA permits, any releases to environmental media from a permitted unit must be documented and corrected.

COMMITTEE MEETINGS AND PRESENTATIONS

In support of this study, the committee obtained information and perspectives from a number of sources. In addition to presentations by several organizations within the Army, a representative of the DDESB, and a number of technology vendors, the committee invited presentations from the U.S. EPA, and representatives from two states authorized under RCRA, the Pennsylvania Department of Environmental Protection and the Alabama Department of Environmental Management. There were also presentations by representatives of the California Communities Against Toxics, Cease Fire! Campaign, and Environmental Patriots of the New River Valley. These presentations, held in August, October, and December 2017, were all simultaneously webcast, which allowed the public to hear the presentations and committee questions and answers in real time. Appendix A of this report identifies the various presentations made to the committee.

REPORT STRUCTURE

Chapter 2 describes the DoD demilitarization enterprise. It outlines organizational responsibility within the DoD, describes the demilitarization stockpile (i.e., locations, types of munitions, amounts); identifies types of explo-

[19] T.L. Chiapello, executive director, DDESB, "Department of Defense Explosives Safety Board (DDESB) Organization, Functions, and Approvals," presentation to the committee, December 11, 2017.

[20] In the course of its work the committee engaged with representatives of the California Communities Against Toxics, the CeaseFire Campaign, the Center for Public and Environmental Oversight, and the Environmental Patriots of the New River Valley.

sives, propellants, and related materials, including materials containing or contaminated with energetic compounds; and describes components of environmental concern (e.g., energetic compounds, metals). Further, it specifically identifies munitions for which OB/OD are and are not being used.

Chapter 3 summarizes conventional OB/OD technologies conducted under RCRA permits.

Chapter 4 provides summary descriptions of alternative technologies. These include chemical and physical treatment (e.g., hydrolysis, cryofracture), CB, CD, partial processing steps, recycling and reuse, and emerging technologies.

Chapter 5 presents the evaluation criteria used by the committee to compare and contrast OB and OD with alternative technologies.

Chapter 6 addresses environmental permitting, both for OB and OD and for alternative technologies.

Chapter 7 addresses the potential applicability of the alternative technologies described in Chapter 4 to the stockpile munitions that are currently being demilitarized using OB or OD. This chapter offers examples of candidate technology combinations and whole munition processes that are alternatives to OB/OD.

Chapter 8 presents a comparative evaluation of demilitarization technologies, including health and safety, environmental impacts, capacity and throughput, public opposition and acceptance, cost and other attributes, as described in Chapter 5.

Chapter 9 discusses barriers and other considerations that may impact the full-scale deployment of alternative technologies.

Appendix A provides a summary of the committee's activities during this study.

Appendix B presents the draft criteria for use when considering alternative technologies that were provided by the Cease Fire! Campaign.

Appendix C discusses the Military Munitions Rule.

Appendix D provides a broader discussion of the background of public opposition to OB and OD that resulted in this study.

Appendix E provides biographical information about the committee members.

Appendix F is an acronym list.

REFERENCES

DoD (U.S. Department of Defense). 2000. *Department of Defense Joint Demilitarization Technology Program, June 2000, A Report to Congress*. Washington, D.C.: Joint Demilitarization Program.

DoD. 2006. *Strategic Plan: The Demilitarization Enterprise, FY 2007-12*. Picatinny Arsenal, N.J.: PM, Demilitarization.

EPA (U.S. Environmental Protection Agency). 2002. *EPA Region III Draft Final Open Burning/Open Detonation Permitting Guidelines*, February 2002. https://www.epa.gov/sites/production/files/201603/documents/rcra_openburnopendet_guide.pdf.

GAO (U.S. Government Accountability Office). 2015. GAO-15-538. *Improved Data and Information Sharing Could Aid in DOD's Management of Ammunition Categorized for Disposal*. Washington, D.C.: U.S. Government Accountability Office.

2

An Overview of the U.S. Army Demilitarization Program, the Demilitarization Stockpile, and Factors Bearing on the Program

ORGANIZATIONAL RESPONSIBILITY

In 2008, the Department of Defense (DoD) designated the Secretary of the Army as the Single Manager for Conventional Ammunition (SMCA; DoD, 2008). Part of SMCA's mission is to "perform life-cycle management for demilitarization of conventional ammunition for the Department of Defense."[1] Policy and oversight of SMCA's activities is delegated to the Assistant Secretary of the Army for Acquisition, Logistics, and Technology. The designated SMCA executor is the Program Executive Office Ammunition, located at Picatinny Arsenal, New Jersey (Joint Ordnance Commanders Group, 2017). As SMCA, the Army has responsibility for demilitarization of excess,[2] obsolete,[3] or unserviceable[4] munitions for all of the military services. Specifically, responsibility rests with the Office of Product Manager for Demilitarization, which is subordinate to Project Director, Joint Services (Figure 2.1).

Day-to-day management of the conventional munition demilitarization enterprise is conducted by the product director for demilitarization (PD Demil) based in Picatinny Arsenal, New Jersey, and execution is coordinated between the Joint Munitions Command (JMC), which owns the seven depots where the conventional munitions stockpile is stored, and the Aviation and Missile Command (AMCOM), which makes decisions on the demilitarization of rockets and missiles (Figure 2.1). JMC manages greater than 90 percent by weight of the demilitarization stockpile consisting of "conventional" munitions such as bombs, mines, and artillery projectiles. AMCOM manages the stockpile of rockets and missiles, which make up about 10 percent by weight of the demilitarization stockpile. JMC and AMCOM coordinate to determine the combination of conventional munitions and rockets and missiles that are to be demilitarized in a given year.

Note that only the seven JMC stockpile storage depots shown in Figure 2.1 and commercial facilities under contract with DoD are considered to be part of the conventional munitions demilitarization enterprise. Other JMC installations, including munitions production facilities such as the Radford, Holston, Milan, and Iowa Army Ammunition Plants, are not considered part of the demilitarization enterprise and are not within PD Demil's managerial purview. However, all of the installations shown in Figure 2.1 have permitted open burning or open detonation (OB or OD) units. In fact, as of March 2017, 35 DoD installations, including storage, manufacturing, research, development, testing, evaluation, and training facilities, had permitted OB or OD units.[5]

[1] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

[2] A munition is considered as excess if there is more of the item in inventory than required for current training or operational plan needs. The Army expresses this information in the Total Army Munitions Requirement (TAMR). If there is more of an item in storage than required by the TAMR, the overage is considered excess. Considerable inventory of select munitions may be retained in field service accounts for training needs. Other services have a similar process. As the TAMR changes to reflect new operational and training requirements, the number of munitions deemed to be excess fluctuates. PD Demil told the committee that munitions are being placed into and taken out of the stockpile all the time.

[3] A munition is considered obsolete if the weapon system that fired that munition is no longer in service (for example, 8-inch artillery projectiles) or if improved munitions have been developed and fielded in sufficient quantities such that the older munitions are no longer required (one example is new tank projectiles that make existing projectiles obsolete).

[4] A munition is considered unserviceable for the Army if it is assigned a condition code other than A-E (A means fully serviceable; E means requiring only a limited expense or effort to restore; and codes continue through the letter N). The Air Force and Navy have separate definitions for what they consider serviceable, but they are still based on condition codes. Condition codes are determined and assigned by Quality Assurance Specialist (Ammunition Surveillance) (QASAS) personnel.

[5] J.C. King, director for Munitions and Chemical Matters, HQDA, ODASA(ESOH), "DoD Open Burn and Open Detonation (OB/OD)," presentation to the committee, August 22, 2017.

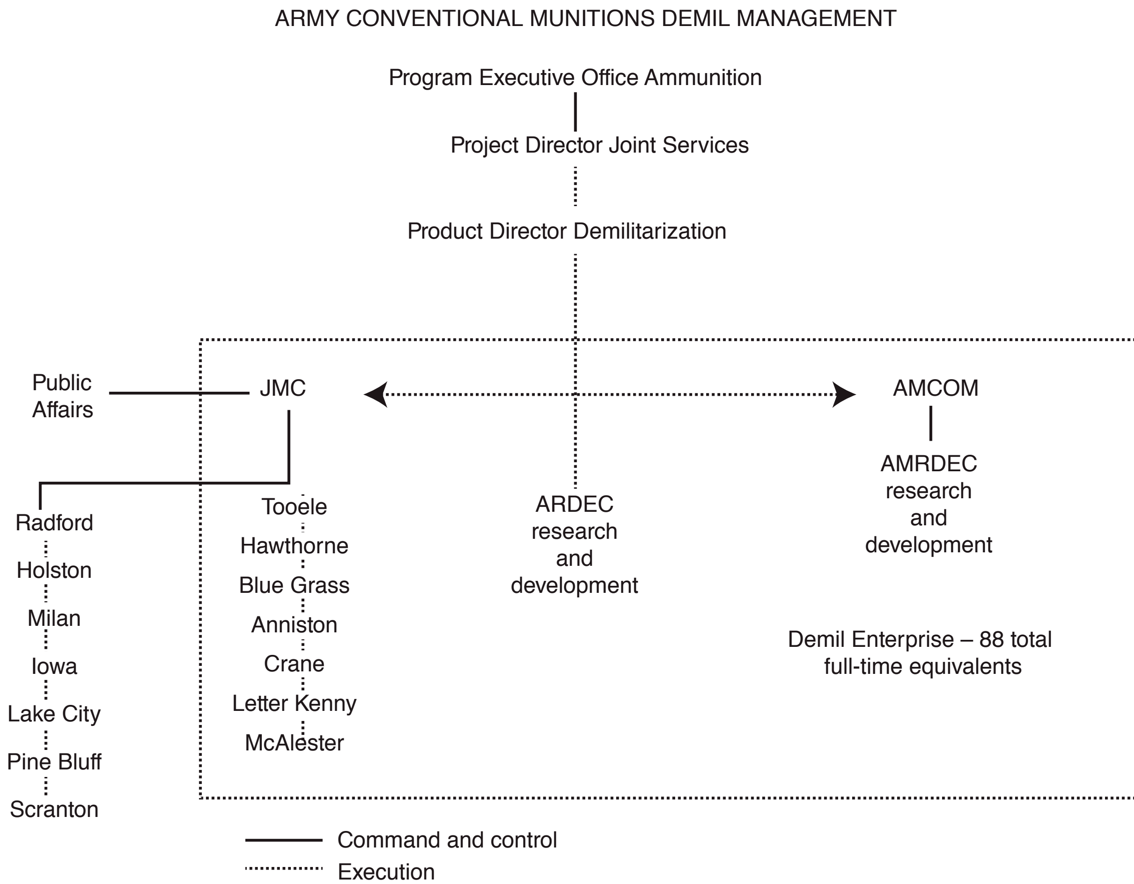

FIGURE 2.1 Executive responsibility for demilitarization of the stockpile of excess, obsolete, and unserviceable munitions rests with the Army's PD Demil. The government organizations comprising the Army's conventional munitions demilitarization enterprise are shown within the dashed box and involve some 88 full-time-equivalent (FTE) employees. Demilitarization is executed by coordination between JMC for conventional munitions and Aviation and Missile Command (AMCOM) for rockets and missiles. NOTE: Radford, Holston, Milan, Iowa, Lake City, Pine Bluff, and Scranton are not part of the demilitarization enterprise; AMRDEC, Aviation and Missile Research Development and Engineering Center; ARDEC, Armament Research, Development and Engineering Center. SOURCE: Committee generated.

THE DEMILITARIZATION STOCKPILE

As of September 30, 2017, the demilitarization stockpile (designated the "B5A account") consisted of 430,987 tons of materiel, including 402,834 tons of conventional munitions and 28,153 tons of rockets and missiles (Figure 2.2). There are more than 7,000 individual types of munitions in the stockpile, each identified by a unique Department of Defense Identification Code (DODIC). The top 10 DODICs, which comprise 32 percent of the stockpile by weight, are shown in Figure 2.3.

Munitions are typically complex systems that include propellant, fuzing with a detonator, and a casing that holds the high explosives. Some munitions are designed to hold and dispense submunitions that have their own fuzing and explosives. For example, DODIC munitions D563 and D864 (the second and third munitions shown in Figure 2.3), comprising greater than 10 percent of the stockpile, are "dual-purpose improved conventional munitions" with projectiles designed to eject and distribute submunitions for anti-armor and anti-personnel effects. Other components requiring special disposal procedures include depleted uranium and smoke-producing munitions. The Army maintains a Munition Items Disposition Action System (MIDAS) database containing details on the composition of the various munitions. The motivation for the development of MIDAS was to facilitate permitting of OB/OD units as well as to reduce the use of OB/OD through reclamation, recycling, and reuse (R3).[6]

[6] J. McFassel, product director for demilitarization, PEO AMMO, "Munitions Items Disposition Action System (MIDAS)," presentation to the committee, December 11, 2017.

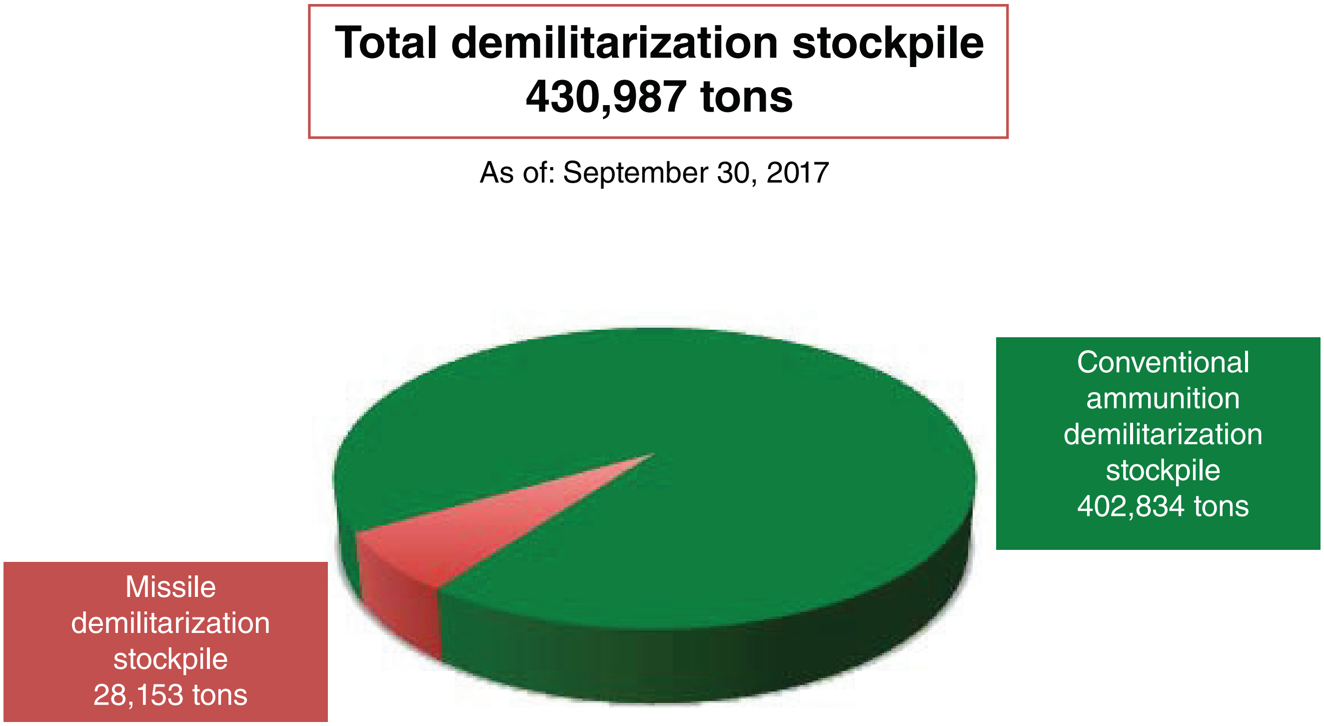

FIGURE 2.2 The total weights of conventional munitions, rockets, and missiles in the demilitarization stockpile as of September 30, 2017. SOURCE: Adapted from figure, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee, October 23, 2017.

Munitions Input into the Demilitarization Stockpile by Fiscal Year (tons)

Each year, new excess, obsolete, and unserviceable munitions are placed into the demilitarization stockpile. Figures 2.4 and 2.5 show the total inflow (termed "generations" by the Army) of rockets and missiles, and conventional munitions respectively into the stockpile at the end of each fiscal year from FY2008 to FY2017. Rockets and missiles are typically accounted for by number, while the quantity of conventional munitions is typically denominated in tons. Also shown are the quantities that had been expected and planned for in each fiscal year for comparison.

Over the past 5 years, the average number of rockets and missiles added to the stockpile was about 86,600 per year, while the average quantity of conventional munitions added was 53,700 tons per year. While planned-for and actual additions to the stockpile have sometimes diverged substantially in the past, especially in FY2009 when a large number of TOW missile training devices were added to the demilitarization account with little notice, PD Demil believes that in recent years the agreement between the two has improved, and believes that this is not a major concern for the future.[7] According to PD Demil, accurate planning with regard to generations of course enables greater efficiency in allocating resources and manpower to execute the demilitarization workload.

End-of-Year Demilitarization Stockpile by Fiscal Year (tons)

Figure 2.6 shows the net demilitarization stockpile of both conventional munitions and rockets and missiles (the latter converted from count by number to tons) remaining at the end of the fiscal years 2008-2017. After reaching a peak at the end of FY2011, the net stockpile has declined by an average of about 5 percent (28,000 tons) per year from FY2011-FY2017.

Stockpile Storage Locations

As mentioned above, the demilitarization stockpile is stored at seven depot locations around the continental United States, as shown in Figure 2.7. These seven sites, along with the associated industrial sites shown in Figure 2.7, are the focus of this report.

Stockpile munitions may be treated at one of the stockpile sites, whether by OB/OD or by an alternative technology, or they may be shipped to a contractor site for treatment with an alternative technology. According to PD Demil, contractor sites are not authorized by the Army to treat munitions by OB/OD.

[7] *Strategic Plan: For the Demilitarization Enterprise*, document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 25, 2018.

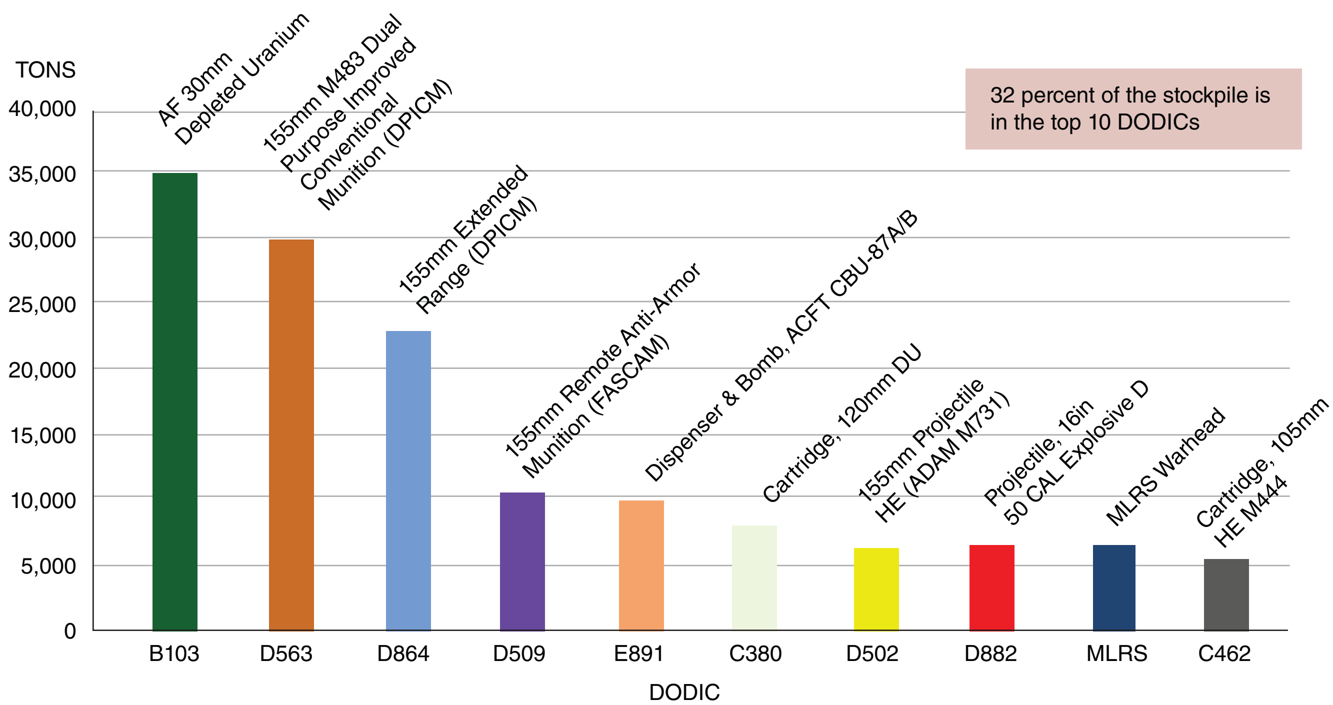

FIGURE 2.3 Major demilitarization stockpile munitions in tons. There are more than 7,000 different types of munitions in the demilitarization stockpile. The top 10 munitions (shown here) comprise 32 percent of the total by weight. SOURCE: J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

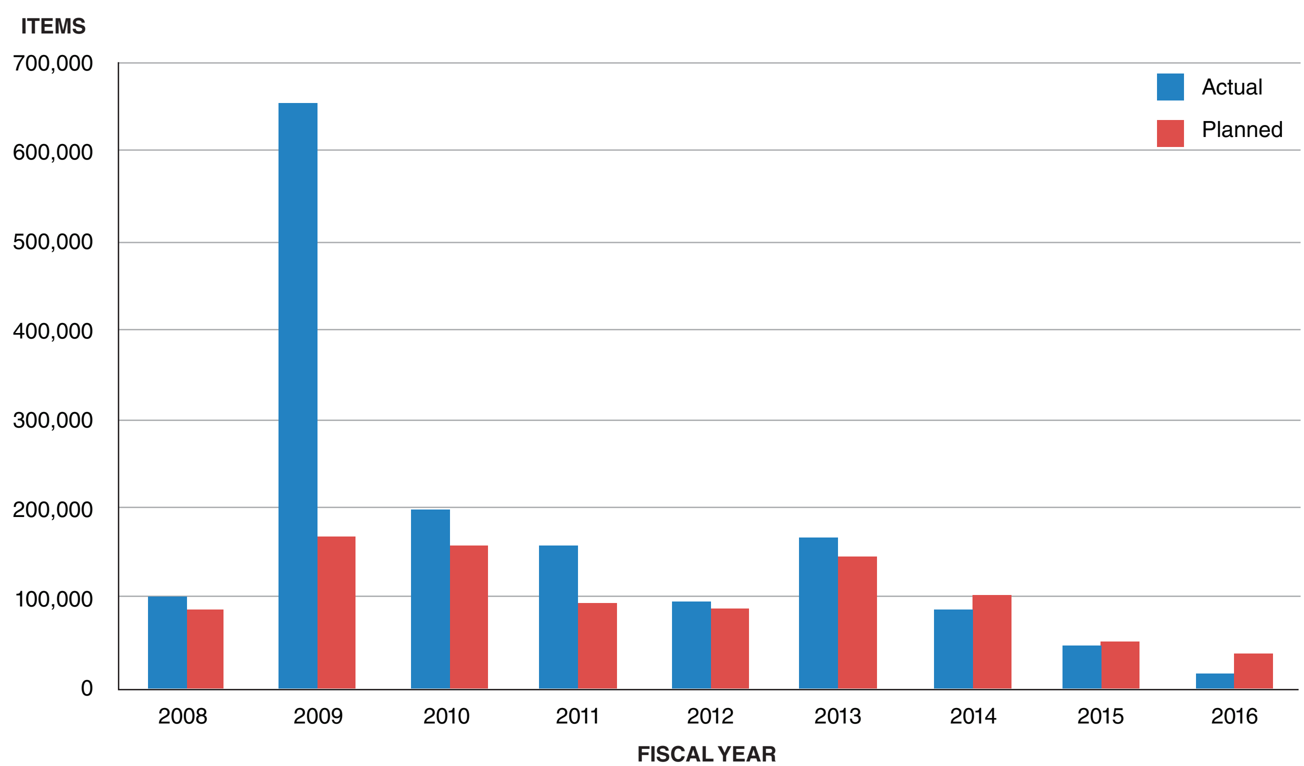

FIGURE 2.4 Rocket and missile input (by number) into the demilitarization stockpile by fiscal year, compared with the number that had been planned for. SOURCE: Derived from data provided by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on November 13, 2017.

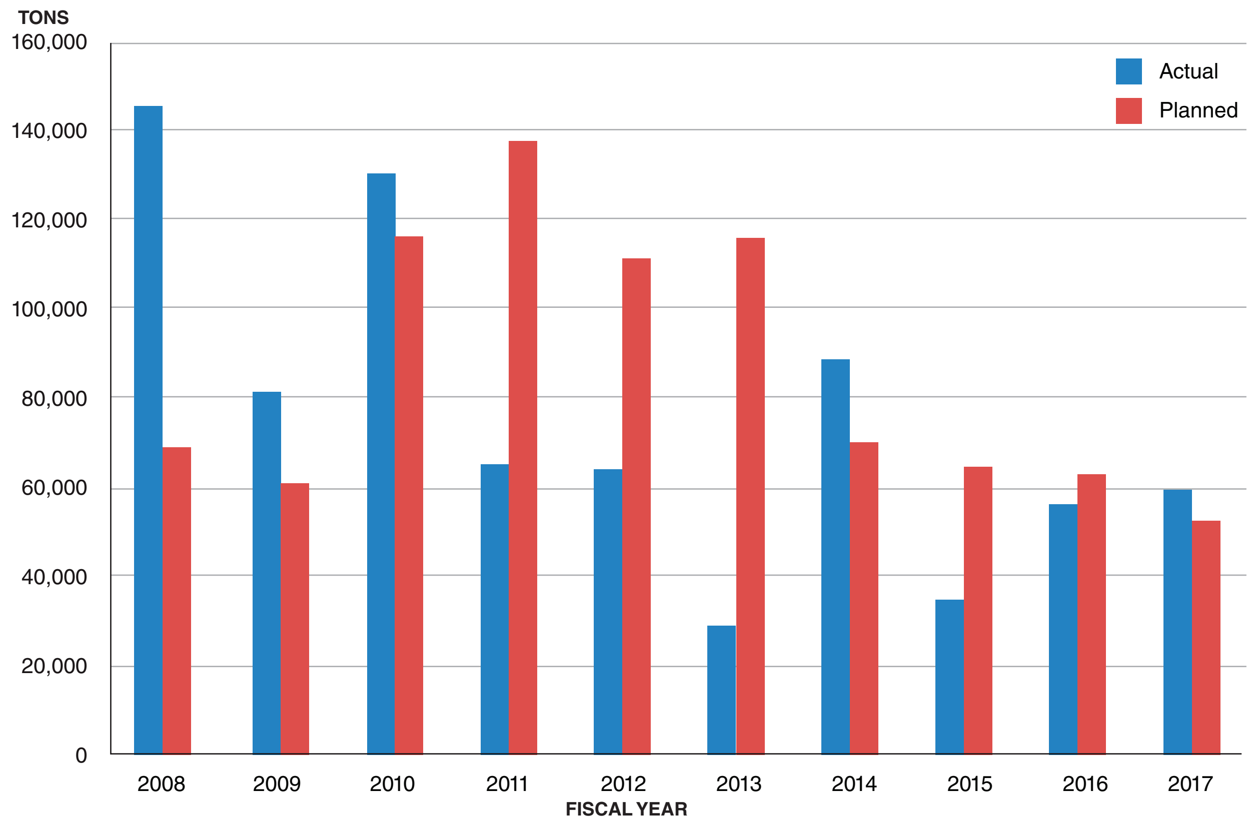

FIGURE 2.5 Munitions input (in tons) into the demilitarization stockpile by fiscal year, compared with the amount that had been planned for. SOURCE: Derived from data provided by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on November 13, 2017.

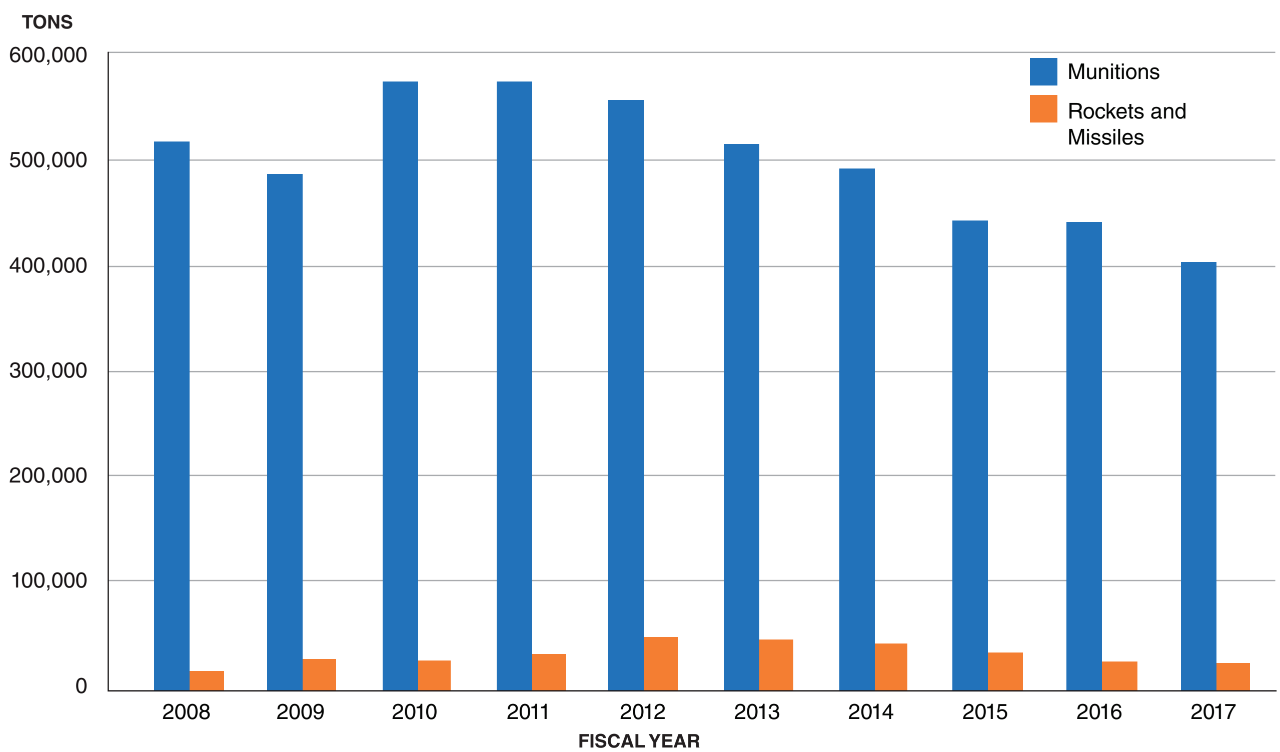

FIGURE 2.6 End-of-fiscal-year munitions and missile stockpiles, FY2008-FY2017. These are net amounts of conventional munitions, rockets, and missiles (number of individual rockets and missiles converted to tons) remaining at the end of each fiscal year, after new rockets and motors were received and scheduled rockets and motors were demilitarized. From a peak in FY2011, the net stockpile has declined by an average of about 5 percent per year. SOURCE: Derived from data provided by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on November 13, 2017.

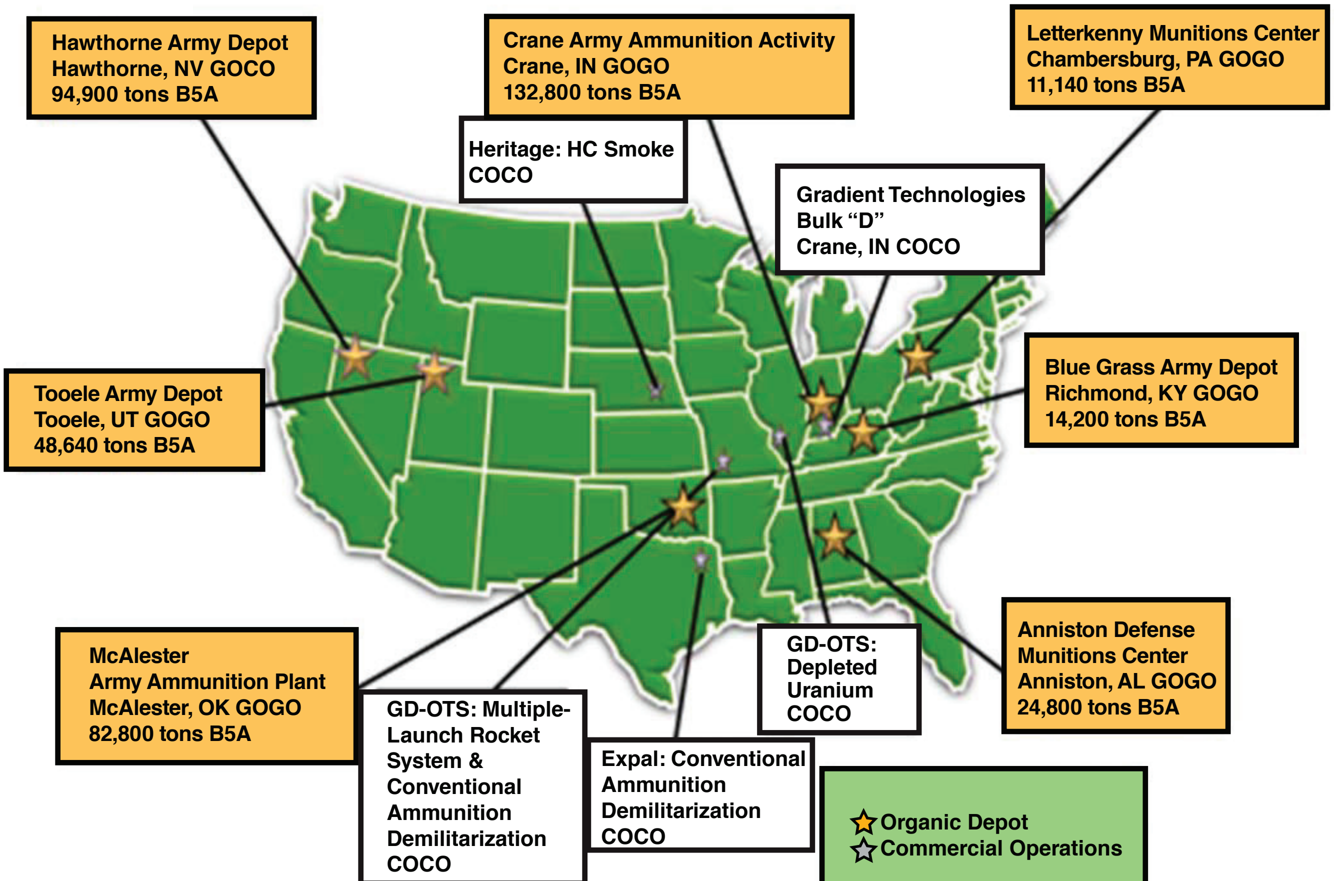

FIGURE 2.7 Army conventional stockpile and demilitarization locations in the continental United States. The Army Demilitarization Enterprise includes the seven U.S. Army depot installations (larger gold stars) where the conventional munitions stockpile (B5A account) is stored, along with a small number of industrial sites that demilitarize munitions by alternative technologies to OB/OD (smaller silver stars), as of February 2018. NOTE: COCO: contractor owned, contractor operated; CONUS: continental United States; GD-OTS: General Dynamics Ordnance and Tactical Systems; GOCO: government owned, contractor operated; GOGO: government owned, government operated. SOURCE: "CONUS Demil Industrial Base," document provided by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on April 9, 2018.

Six of the seven stockpile storage sites are government owned and government operated (GOGO). The exception is Hawthorne Army Depot in Nevada, which is government owned and contractor operated (GOCO). The munition production plants shown above in Figure 2.1, which are not part of the conventional munitions demilitarization program but do conduct OB/OD, are GOCOs. According to the director of public and Congressional affairs, JMC, due in part to the steady encroachment of development and population near these GOCO ammunition plants and the quantity of material they treat by OB, these OB operations have been the focus of more opposition from neighbors and public interest groups than OB operations at the stockpile depots, which burn less material and tend to be more isolated.[8]

DEMILITARIZATION PROGRAM FUNDING

Figure 2.8 shows the annual funding for the Army's conventional munitions demilitarization program from FY2008 to FY2018.

Overall funding increased from $134 million in FY2008 to about $251 million in FY2018, although funding has been highly variable over the years. The Army projects that the demilitarization stockpile will begin growing again because additions to the stockpile will exceed the quantities that can be demilitarized with the funds provided (DoDIG, 2017). The National Defense Authorization Act for Fiscal Year 2019 (H.R. 5515), in reconciliation as this report was completed, granted the Army request of $158 million for demilitarization activities.[9]

[8] January 16, 2018, telephone interview with J. Barati, director of public and Congressional affairs, JMC, and the committee.

[9] H.R.5515 - John S. McCain National Defense Authorization Act for Fiscal Year 2019, https://www.congress.gov/bill/115th-congress/house-bill/5515.

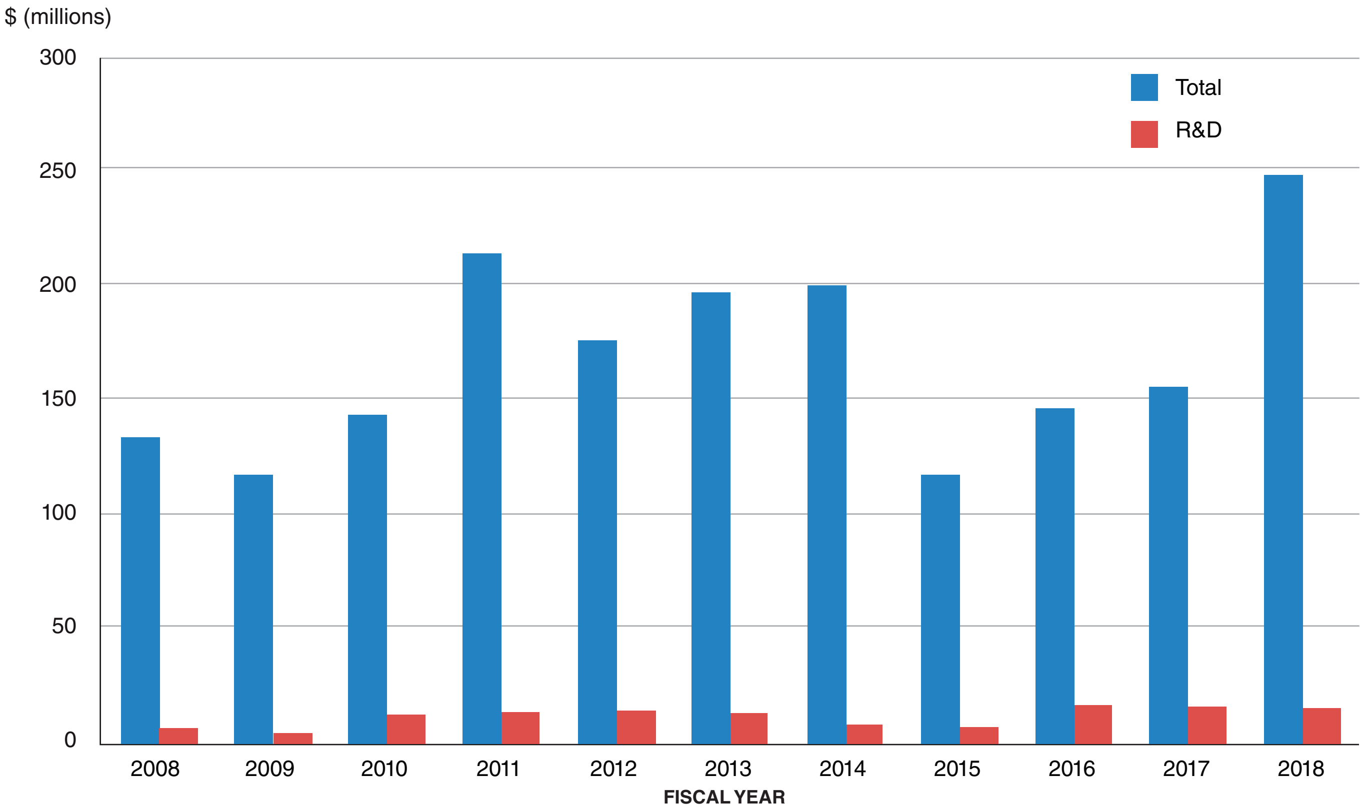

FIGURE 2.8 Demilitarization program funding, FY2008-FY2018. Funding for the Army's conventional munitions demilitarization program has generally increased since FY2008 but has been highly variable. There is a budget (orange bars) for research, development, testing, and evaluation of technologies. SOURCE: Derived from data provided by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on November 13, 2017.

The demilitarization budget is split roughly half and half between organic operations (Army facilities and personnel) and contractor activities (Figure 2.9). PD Demil stated to the committee that the primary limitation on the quantity of munitions demilitarized is not technological capability or capacity, but rather budget.[10] A December 2013 Army Audit Agency report by the Army Deputy Chief of Staff for Logistics (G-4) stated that the conventional munitions demilitarization program is considered a lower priority by the Army when compared to other needs, such as readiness and operations (GAO, 2015).

Finding 2-1. According to PD Demil, the primary factor determining the quantity of munitions demilitarized in a given year is the budget, not technological capacity or availability.

Overall demilitarization program funding includes a research, development, testing, and evaluation (RDT&E) program currently averaging about $17 million per year. The decision-making process for ranking research projects in the RDT&E program is discussed further below.

Figure 2.9 shows the funding allocation for various aspects of demilitarization execution plan for FY2017 and FY2018, including conventional munitions versus rockets and missiles, and contractors versus organic facilities.

DEMILITARIZATION PROGRAM OPERATIONS

Before munitions enter the demilitarization stockpile (the B5A account), there is a review process to determine whether they may be used for another purpose or sold, as depicted in Figure 2.10. Some munitions in the demilitarization stockpile can be diverted to other uses rather than being disposed of. For example, some artillery projectiles may be suitable for avalanche control operations. Some small-arms ammunition is sent to law enforcement agencies such as the FBI. And munitions can be given or sold to foreign governments for their use (Hrycak and Crank, 2015).

Formulation of the Army's annual demilitarization plan begins with the use of a decision-support tool called the Demilitarization Optimizer (Figure 2.11). PD Demil indicates that the optimizer is designed to maximize the stockpile tonnage that can be demilitarized in a given year

[10] J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee on October 23, 2017.

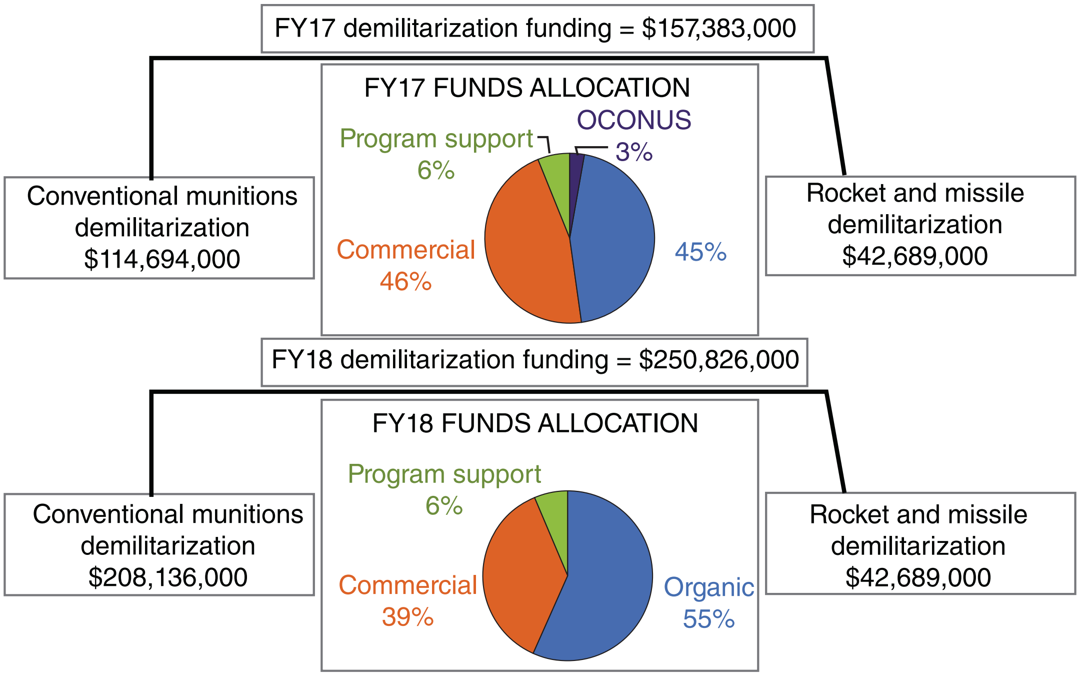

FIGURE 2.9 Funding allocation for various aspects of the demilitarization program budget in FY2017 and FY2018. NOTE: OCONUS: outside the continental United States. SOURCE: *Demil Execution Plan Snapshot*, document provided by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on April 9, 2018.

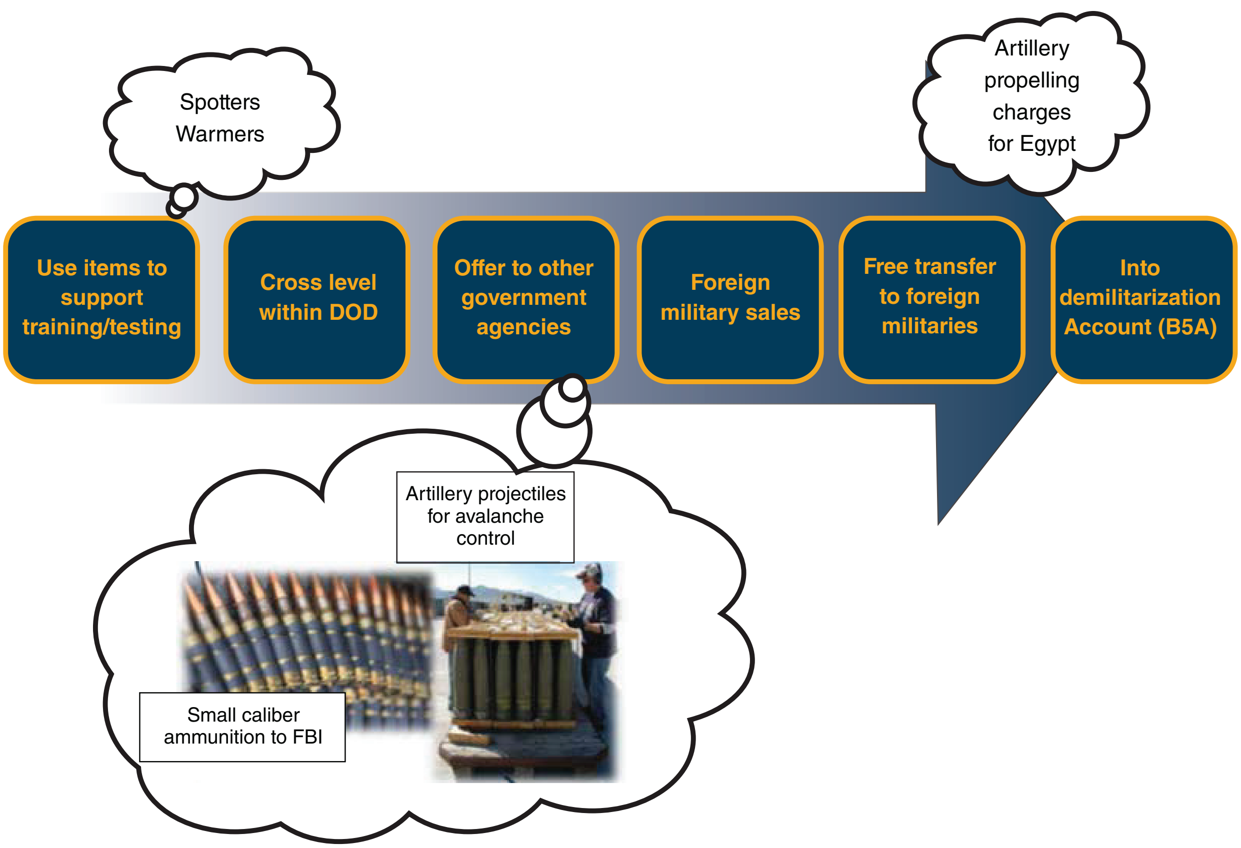

FIGURE 2.10 Alternatives for disposition of excess munitions prior to entering the demilitarization stockpile. NOTE: "Spotters and warmers" refers to the alternate use of projectiles deemed unsuitable for combat use to warm the gun barrel ("warmers" used to prepare the gun for maximum accuracy) and to indicate the point of impact (spotters) for the purpose of adjusting the aiming and trajectory to accurately impact the target. SOURCE: Hrycak and Crank (2015).

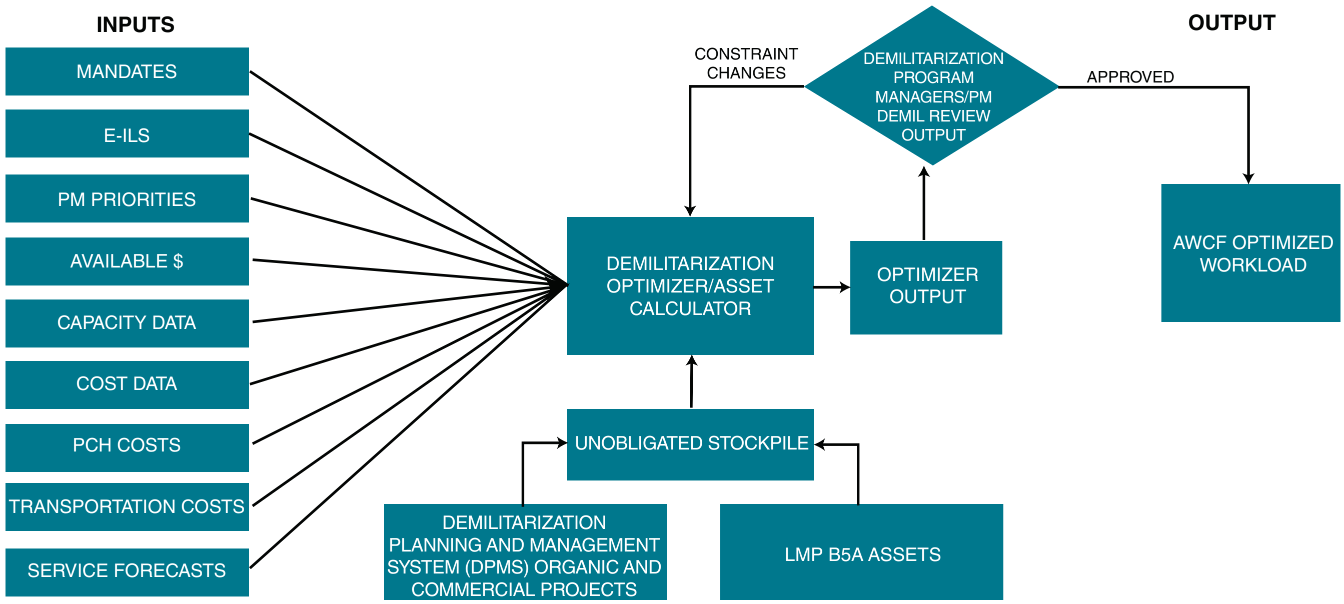

FIGURE 2.11 Schematic diagram of the database Demilitarization Optimizer tool. This tool assists in determining the annual demilitarization workload, and includes a large number of inputs and constraints (see text for further discussion). Minimizing cost/ton given the constraints is the optimization objective. NOTE: AWCF: Army Working Capital Fund; E-ILS: Enterprise Integrated Logistics Strategy (the JMC strategic plan on managing organic installations); PCH: packaging, crating, and handling; LMP: Logistics Modernization Program. SOURCE: U.S. Army, "Demil PMR Optimizer Process," presentation, May 2017.

given the assigned constraints, such as budget.[11] Inputs to the program include mandates such as policies prioritizing the destruction of specific types of munitions and cost data including cost estimates of man-hours per ton. Minimizing cost-per-ton is not an assignable constraint, but rather is the optimization objective. The three most common constraints imposed are (1) Program Objective Memorandum dollars;[12] (2) mandates, such as minimum tons that must be treated per location, MIDAS family, or treatment process; and (3) "no-ship" requirements for munitions designated for OB/OD or incineration.[13] The no-ship constraints are placed in the optimizer to limit transportation of munitions between installations because transportation is considered a non-value-added activity, in addition to being costly. PD Demil estimates that the average transportation cost is $1,000/ton within the continental United States.[14] According to PD Demil, conscious decisions are made to ship assets between organic installations, generally due to lack of capability at the existing site.[15] Since alternative treatment technologies cost more than OB/OD per ton, the use of the optimizer alone will not prioritize the substitution of alternatives for OB/OD in the annual demilitarization workload.

According to the Army, demilitarization decisions about rockets and missiles are made separately using many of the same factors. Rocket and missile motors can pose a stability hazard in long-term storage as the stabilizer in the propellant grain degrades, but would be unlikely to rise to the top of the optimizer list based on gross weight alone. Nevertheless, PD Demil demilitarizes several types of rocket and missile motors each year, in part to remove potentially unstable motors from the stockpile as expeditiously as possible. The annual execution process is depicted in Figure 2.12.

DEMILITARIZATION PROGRAM RESEARCH, DEVELOPMENT, TESTING, AND EVALUATION

As noted above, the Army's demilitarization program maintains an RDT&E program of some $17 million per year (FY2017) for the exploration and enhancement of demilitarization technologies. There is a well-defined, multistep procedure for reviewing and selecting RDT&E projects (Figure 2.13) based on specific criteria. Central to the process is an integrated product team that evaluates the proposals quantitatively according to the set of criteria.

[11] U.S. Army, "Demil PMR Optimizer Process," presentation, May 2017.

[12] A Program Objective Memorandum is a proposal from the Services and Defense Agencies to the Office of the Secretary of Defense (OSD) concerning how they plan to allocate resources to accomplish their missions over the next 5 years.

[13] U.S. Army, "Demil PMR Optimizer Process," presentation given in May 2017.

[14] This estimate includes shipping costs as well as the costs of removing the items from storage, preparing them for shipping, and then reversing the process on the receiving end. J. McFassel, PD Demil, in an e-mail to the committee on September 6, 2018.

[15] May 9, 2018, conference call with J. McFassel, product director for demilitarization, PEO AMMO, the committee, and Jim Myska, study director.

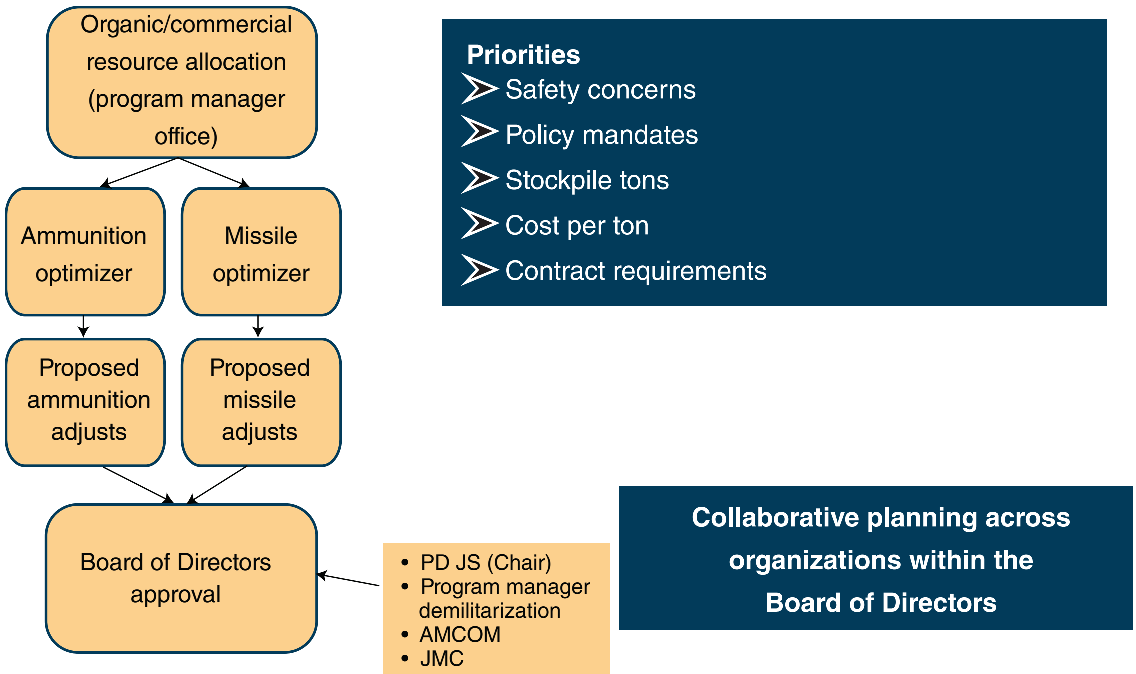

FIGURE 2.12 The decision process for determining the annual demilitarization plan for stockpile munitions. SOURCE: Hrycak and Crank (2015).

Three categories of criteria are used to prioritize proposed RDT&E projects for funding. Within each category, criteria are given a weighting from 1 to 5 (highest):[16]

1. *Financial*: This includes degree to which demilitarization cost is reduced compared to the previous method, the total project cost, and return on investment;
2. *Execution*: This includes the total tonnage affected in the stockpile, total length of the project, and the degree to which demilitarization throughput is increased; and,
3. *Technical*: This includes the degree to which the project increases the technology readiness level or manufacturing readiness level of a technology, the degree to which it addresses a capability gap, the degree to which it increases efficiency, and the degree to which it is omnivorous—that is, possesses the ability to demilitarize multiple types of munitions with a single set of equipment or processes.

In FY2017, 21 RDT&E projects were being supported (Table 2.1). Note that all have some degree of maturity; PD Demil stated that it does not fund "science projects" under this program.

There is an indirect connection between the annual demilitarization program plan and the evaluation of RDT&E project proposals. Every 6 months, PD Demil conducts an analysis of the top 400 munitions in the stockpile (by weight), and this document serves as a source document for both the demilitarization optimizer (see Figure 2.10) and the RDT&E program.[17] The Army tries to include at least one rocket or missile motor type in the RDT&E projects each year.[18] Finding alternatives to OB/OD is not a criterion used in selecting RDT&E projects for funding.

Finding 2-2. Despite the Army's stated strategic goal of replacing OB/OD with alternative contained treatment technologies, reducing the use of OB/OD is not an explicit criterion used to evaluate projects in PD Demil's RDT&E program.

Recommendation 2-1. The Army should include the potential to reduce the use of open burning and open detonation as a criterion used to evaluate candidate projects in Office of the Product Director for Demilitarization's research, development, test, and evaluation program.

[16] O. Hrycak, chief engineer, PD Demil, PEO AMMO, Demil 2017, RDTE FY17 Project Selection Process, September.

[17] September 27, 2017, conference call with Todd Kimmell, committee chair, Doug Medville, committee vice-chair, Jim Myska, study director, and Greg Eyring, consultant.

[18] September 27, 2017, conference call with J. McFassel, product director for demilitarization, PEO AMMO, the committee, and Jim Myska, study director. The number of rocket and missile motors destroyed each year will likely increase when the facility designed for this purpose at Letterkenny Munitions Center comes on line.

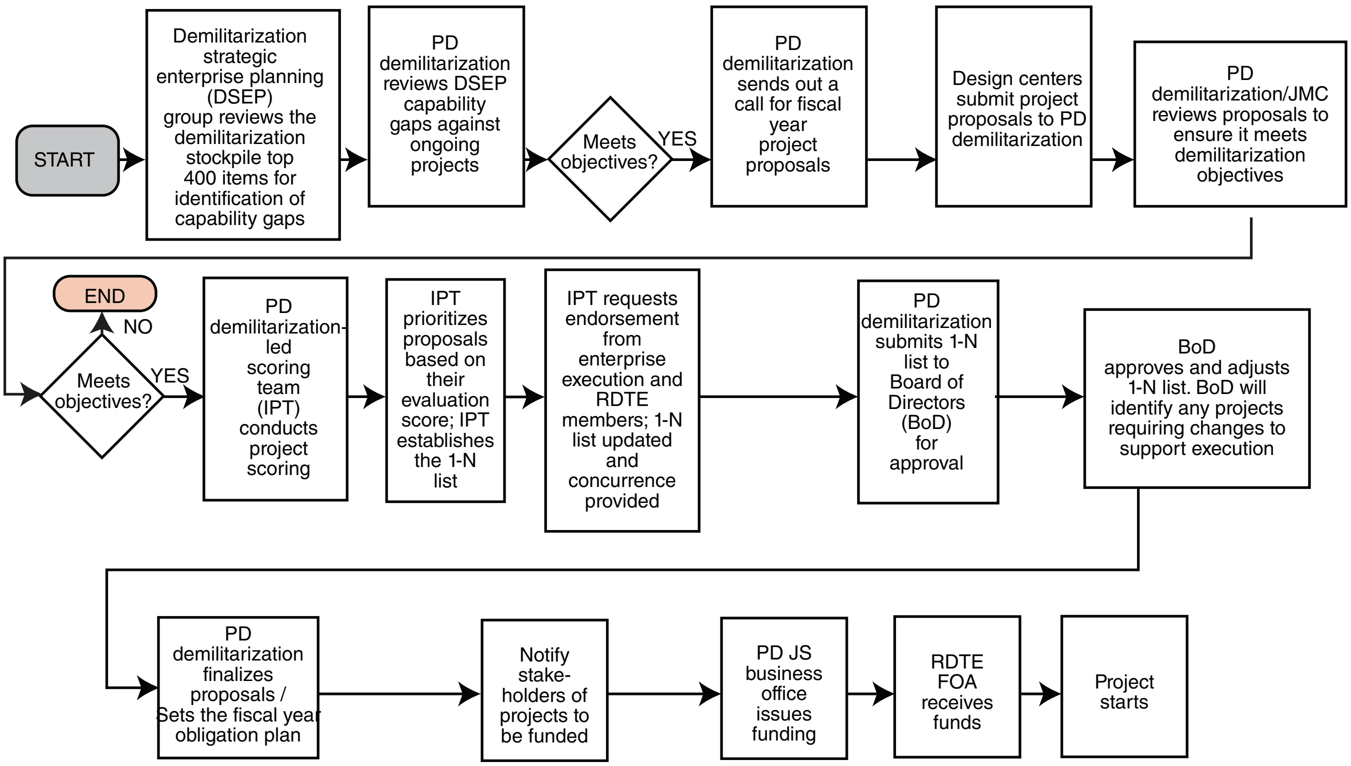

FIGURE 2.13 Research, development, testing, and evaluation project selection process. SOURCE: O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO, and J. McFassel, product director for demilitarization, PEO AMMO, "Demil RDTE FY17 Project Selection Process," presentation given September 28, 2017.

ARMY CONVENTIONAL DEMILITARIZATION PUBLIC AFFAIRS PROGRAM

The potential for increased scrutiny of OB/OD resulting from the concerns of the public near sites that conduct OB/OD operations and congressional inquiry has been a motivator for use of alternative treatment technologies. Testimony to this committee by public interest groups has confirmed that these groups not only want to see OB/OD phased out, but also want to have a voice in the alternative treatment technologies that are selected.[19] Experience has shown that engaging the public can expedite decision processes for technology selection and deployment and improve system designs and operations. In recognition of this, the committee considers public confidence in technologies and technology management as a criterion for the evaluation of alternative technologies in this report, as discussed in Chapter 5.

The Public and Congressional Affairs Office that manages public affairs for the seven conventional munitions stockpile sites discussed in this report is attached to, and funded by, the JMC headquarters at Rock Island Arsenal (see Figure 2.1). The director of the Public and Congressional Affairs Office reports to the JMC chief of staff, and the relationship to PD Demil and the Demilitarization Enterprise is informal. This same office, which has a total of eight staff (six government and two contractors), also oversees public affairs at eight other JMC installations, including the Army munitions production plants (Holston, Milan, Radford, and Iowa) that are not considered part of the Demilitarization Enterprise (see Figure 2.1).

The Public and Congressional Affairs Office typically responds to specific calls for assistance by a site commander, Congress, media, or public concerns. Consistent with Army Regulation R 360-1, *The Army Public Affairs Program*, that office sees its role as providing accurate information to encourage confidence in, and support for, Army activities.[20] Specifically with regard to OB/OD, this can involve providing information that is intended to counter negative public perceptions. One example is in the Open Detonation/Open Burning Tactical Communication Plan at Crane Army Ammunition Activity (CAAA):

> Educate and influence key stakeholders at the local, state and national level related to the issue of open burning and open

[19] In the course of its work the committee engaged with representatives of the California Communities Against Toxics, the CeaseFire Campaign, the Center for Public and Environmental Oversight, and the Environmental Patriots of the New River Valley.

[20] January 26, 2018, interview with Justine Barati, director, Public and Congressional Affairs Office, the committee, Jim Myska, study director, and Greg Eyring, consultant.

TABLE 2.1 The FY2017 Demilitarization RDT&E Project Scoring and Ranking for 21 Funded Projects

Project Type	Project Name	Score	Rank
NS	Ammonium Perchlorate Rocket Motor Destruction (ARMD) Facility Multiple Rocket Motor Firing	3.6	1
OG	Castalia Assessment	3.4	2
OG	Static Detonation Chamber (SDC) Assessment	3.2	3
NS	Reactive Armor Tile Thermal Treatment	3.1	4
OG	Area Denial Artillery Munition (ADAM) Cryogenic Processing	2.98	5
OG	APE 1236 Rotary Kiln Incinerator (RKI) Feed System Upgrade	2.94	6
OG	Copperhead Disassembly and Demilitarization	2.9	7
OG	Navy Gun Explosive D Cutting and Washout	2.88	8
OG	Riot Analysis of Alternatives (AoA)	2.8	9
OG	OB/OD Emission Testing	2.78	10
OG	Engine Starter Cartridge Static Firing	2.7	11
OG	Rockeye Download	2.62	12
NS	Cryogenic Demilitarization of Rockeye	2.6	13
NS	CS Riot Pilot Scale Thermal Testing	2.6	14
NS	Static Fire Emission Characterization	2.4	15
OG	Automated Disassembly and Size Reduction of Armor Tiles	2.4	16
NS	MK46 Torpedo	2.2	17
NS	G826 Grenade Demil	2.1	18
OG	Red Phosphorous Demonstration	2.08	19
NS	D561 Improved Conventional Munition Demilitarization	1.9	20
NS	Bulk Energetic Confined Burn	1.6	21

NOTE: The process is based on the criteria discussed in the text. NS, new start; OG, ongoing. SOURCE: O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO.

> detonation (OB/OD) in an effort to counter current and future misinformation about the OB/OD process. By being transparent, and by more effectively educating local communities and local/state/national leadership, CAAA will build support for all operations at CAAA, including demilitarization effort, specifically, OB/OD (emphasis added).[21]

Thus, the Public and Congressional Affairs Office is not designed to focus on public engagement or two-way communication. This approach has implications for public acceptance of potential alternative demilitarization technologies, as discussed further in Chapter 9.

ARMY SAFETY PROGRAM

The overall structure and capability of the Army demilitarization safety program follows the generally accepted norms and guidelines of many industrial safety and occupational health systems (NSC, 2001). Acute risks associated with the conventional munitions demilitarization safety effort are overseen by the U.S. Department of Defense Explosives Safety Board (DDESB), and this body has an established framework that includes policies, directives, standards, instructions, and approvals.[22]

The DDESB has established a tiered management system, or policy framework, that has four distinct levels:[23]

1. A policy level as outlined by DoD Directive 6055.09E, "Explosives Safety Management" (DoD, 2017a);
2. A program level as outlined by DoD Instruction 6055.16, "Explosives Safety Management Program" (DoD, 2017b);
3. DoD Manual 6055.09-M, "Department of Defense Ammunition and Explosives Safety Standards"; and[24]
4. A risk management integration process as documented by the Chairman of the Joint Chiefs of Staff

[21] As discussed in J. Barati, director, Public and Congressional Affairs Office, Joint Munitions Command, "Public Engagement by the Joint Munitions Command (JMC)," presentation to the committee, December 11, 2017; and emphasized in the objectives outlined in CAAA, 2016.

[22] T. Chiapello, executive director, DDESB, "Department of Defense Explosives Safety Board (DDESB) Organization, Functions, and Approvals," presentation to the committee on December 11, 2017.

[23] Ibid.

[24] DoD Manuals (6055.9-M, DoD Ammunition and Explosives Safety Standards (Volumes 1-8)), https://www.wbdg.org/ffc/dod/manuals.

Instruction 4360.01, which operationalizes explosives safety (CJCSI, 2014).

The DDESB addresses acute risk and limits its overview to aspects of explosives and chemical agent safety. Its approvals include, but are not limited to: hazard classifications, protective construction designs, and site plans, including the operating conditions or operating license.

Through the DoD acquisition process as outlined in DoD Instruction 5000.02, dated January 7, 2015, deliberate checks and balances are in place to ensure that all personnel, military, civilian, and in the surrounding community, will be appropriately protected from harm. As with any hazardous operation, the safety of personnel depends on execution per procedure (including appropriate and adequate training) and the safety leadership and culture.

A number of incidents[25] have occurred during OB/OD and alternative technology operations since 2004 (Table 2.2). During this period, hundreds of thousands of tons of munitions were demilitarized. A majority of the incidents involved workers performing preparation activities or physical operations on the munitions: accidental[26] detonation during fuze removal operations, accidental deflagration during cutting and size reduction of rocket motors and removal of energetics, accidental injuries associated with disassembly, handling, and download of submunitions, and accidental detonation during explosives removal are examples. Fewer incidents occurred during OB/OD operations than during contained disposal technology (CDT) operations and RDT&E activities.

Munitions demilitarization by any means requires that the munitions be handled, moved, prepared for OB or for OD, and for alternative technologies and combinations of these technologies, may require some disassembly and other processing steps, prior to energetics destruction in a contained chamber. In general, as the number and complexity of processing steps increases, the potential for accidental detonations, deflagrations, and fires also increases. The need for munitions handling and processing as part of any demilitarization operation will depend on several factors: the munition configuration and its internal components, its shock sensitivity, the degree to which manual vs. automated (robotic) handling and processing is involved, and the number of opportunities for accidents to take place (a greater number of processing steps may result in a higher probability of an accident). Alternative demilitarization technologies that involve more manual operations in handling and preparation than OB/OD are likely to pose greater safety risks, while those that are highly automated may pose reduced safety risks compared with OB/OD, at least to personnel.

In its 2018 Strategic Plan,[27] the PD Demil Vision commits the organization "to continuously modernize for safety." The committee recognizes that both the demilitarization operations and the RDT&E activities are generally hazardous. The committee considers the accidents (incidents) listed in Table 2.2 to be regrettable and preventable. The Army and its contractors have developed safety procedures for current operations, and the committee assumes that these procedures will be developed for alternative technologies. In addition, safety and health are being addressed in the DoD Acquisition work processes. The Army's safety processes are certified by the American National Standards Institute.

Finding 2-3. The Army demilitarization program appears to have instituted an effective safety management program.

DEMILITARIZATION TECHNOLOGIES USED TO TREAT THE STOCKPILE

Current demilitarization methods include the following:

- OB/OD;
- Explosives removal;
- Disassembly;
- Cutting and resizing;
- Incineration and contained burn;
- Contained detonation; and
- R3.

Specifics of the demilitarization technologies that fall in these categories are discussed in detail in Chapter 4.

PD Demil presented to the committee four strategic goals of the demilitarization enterprise:

1. Efficiently reduce the demilitarization stockpile by maximizing use of the capacity of the organic and commercial industrial base;
2. Continuously improve the efficiency and effectiveness of demilitarization capabilities within the enterprise;

[25] Use of the term "accident" is discouraged in the safety profession, as it denotes that an incident could not have been prevented. Members of the safety profession prefer the use of the word "incident." *Incident:* An *unplanned, undesired* event that hinders completion of a task and may cause injury, illness, or property damage or some combination of all three in varying degrees from minor to catastrophic. Unplanned and undesired do not mean *unable to prevent*. Unplanned and undesired also do not mean *unable to prepare for*. Crisis planning is how people prepare for serious incidents that occur that require response for mitigation. *Accident:* Definition is often similar to incident, but supports the mindset that it *could not have been prevented*. An accident is the opposite of the fundamental intentions of a safety program, which is to find hazards, fix hazards, and prevent incidents. By accepting that accidents have no cause, one assumes that they will happen again (Mottel et al., 1995, pp. 201-202).

[26] Although the committee prefers the term "incident," the term "accident" is used here and in Table 2-2 because it reflects the characterization of the incident by the sponsor.

[27] *Strategic Plan: For the Demilitarization Enterprise*, draft document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 25, 2018.

TABLE 2.2 Incidents Associated with OB/OD and Alternative Demilitarization Technologies from 2004 to 2017

Type of Incident	Serious Injury, Death, or Equipment Damage	Estimated Cost to Government	Organization	Date
Accidental detonation of buried submunition during prepping excavation operations on range	Serious injury to one operator	Less than $500,000 to replace excavation equipment	OB/OD Operations	2004
Accidental detonation during explosives removal and chemical conversion operations	Moderate to serious damage to process equipment and building	More than $500,000 in equipment and building damage	CDT RDT&E	2005
Accidental detonation of explosives during accessing of energetics in preparation for treatment	Moderate to serious damage to equipment and facilities	More than $500,000 in equipment and building damage	CDT Operations	2006
Accidental fire during flashing of energetic residues from demilitarized metal components	Moderate to serious damage to equipment and facilities	More than $500,000 in equipment and building damage	CDT RDT&E	2009
Accidental injuries associated with the disassembly, downloading, and handling of submunitions during demilitarization processing	Moderate to serious arm, hand, and finger injuries to multiple operators during processing	Unknown cost and lost time to government	CDT Operations	Multiple injuries 2009-2011
Accidental deflagration during energetics recovery for reuse operations	Death of two operators; significant damage to facility and equipment	Unknown cost to government	CDT RDT&E	2010
Accidental detonation of munitions during removal of energetics using ultrasonics	Moderate to serious damage to equipment and facilities	More than $500,000 in equipment and building damage	CDT RDT&E	2012
Accidental deflagration during cutting and size reducing of rocket motors	Significant damage to both equipment and facility requiring replacement of cutting equipment	Unknown cost to government	CDT Operations	2012
Accidental detonations of submunitions during fuse removal operations	Moderate damage to both equipment and facilities	Unknown cost to government	CDT Operations	Multiple events 2012-present
Accidental detonation of submunition during milling operations to remove explosives	Minor damage to equipment and facilities	Less than $500,000 in equipment damage	CDT RDT&E	2014
Accidental premature detonation during range prepping operations	Minor ear injury to two operators due to blast over pressure exposure	Less than $500,000 to update electrical firing equipment on range	OB/OD Operations	2015
Accidental deflagration during removal of energetics from red phosphorus munitions	Minor damage to equipment	Less than $100,000 in equipment damage	CDT RDT&E	2016
Accidental detonation during thermal treatment of submunitions	Moderate damage to equipment	Less than $500,000 in replacement cost	CDT RDT&E	2017

SOURCE: Table derived from data provided by US Army Demil to the committee in August 2017.

3. Implement design for demilitarization for all new and modified conventional ammunition products; and
4. Increase the use of contained ("closed") disposal, resource recovery, and recycling consistent with continuing to ensure minimal exposure of personnel to explosive safety risks.[28]

These four goals are reaffirmed in a Strategic Plan document provided by PD Demil to the committee in May 2018.

[28] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

With regard to the contained disposal technology portion of goal 4, two metrics are offered:

1. "Percentage of annual tonnage of munitions demilitarized using contained disposal technologies. … The metric will be calculated by dividing the total amount of demilitarization conducted using contained disposal technologies at both organic and commercial sites by the total amount of demilitarization executed in a year." It will be based on reports from the depots and industry contractors, to be monitored by JMC and PD Demil. The Army suggests that a year-by-year increase in this percentage will be considered

a success, although no specific target percentages or timetables for reaching them are offered.

2. "Total configurations in the stockpile for which contained disposal technology exists or is feasible. The source of this metric will be the stockpile analysis conducted by JMC Industrial Capabilities Division. It will focus on configurations associated with the top 400 DODICs in the stockpile by weight." The Army says that it should show an increase from the previous year, although once again no specific target numbers or timetables for reaching them are offered. [29]

PD Demil's Strategic Plan is discussed further in Chapter 9.

Below, with regard to strategic goal 4, the quantities of munitions currently demilitarized by OB/OD versus alternative technologies are discussed, along with the Army's rationale for making this choice.

Munitions Demilitarized Organically by Open Burning or Open Detonation

Only organic facilities, not contractors, are authorized to conduct OB/OD operations. According to data supplied by PD Demil,[30] in FY2016 and FY2017 the average quantity of conventional munitions and rockets and missiles demilitarized was 75,474 tons each year. Over that period, the average quantity demilitarized by OB/OD was 23,203 tons per year, or about 30 percent per year.[31] According to DoD, this represents a substantial reduction in the use of OB/OD as a demilitarization method compared to the mid-1980s, when it is estimated to have been used for about 80 percent of munitions, rockets, and missiles.[32]

Finding 2-4. According to data provided to the committee by PD Demil, the use of OB/OD as demilitarization treatment methods has declined from an estimated 80 percent of demilitarized munitions in the mid-1980s to an average of about 30 percent in recent years.

Only a portion of this decline in the use of OB/OD is due to the use of alternative contained burn or contained detonation technologies; another factor is the increased use of munitions disassembly enabling the recovery and reuse of energetics and other munition components.

According to PD Demil, the top reasons stated by the Army for continued use of OB/OD for certain munitions and rockets and missiles were

- *Personnel safety*: Safety issues may arise from increased handling required by alternative technologies.
- *Characteristics that make treatment in contained systems difficult*: These may be a result of the munition's size, design, or composition, or they may be due to the type of explosive or energetic compounds in the munition.
- *Cost-effectiveness*: According to Army demilitarization management,[33] the direct costs/ton of OB/OD are lower than the costs of contained treatment technologies.
- *No on-site alternative treatment capability available*: This reason was frequently cited but may be largely a cost issue (packaging, crating, handling, and transporting the munition to a site where alternative treatment is available, or building an alternative treatment capability at a site where it does not presently exist).
- *Emergency situations*: Munitions that are deemed unstable or incapable of being transported must be treated by OB or OD.[34]

One example of a munition characteristic that can make treatment in contained systems challenging is shaped charges that are designed to penetrate armor plating with an explosively formed jet of hot gases and molten metal created by the detonation of the specially shaped explosive. As such, even though they may have a relatively small net explosive weight, shaped charges detonating in a contained detonation or incineration chamber or vessel are likely to damage the chamber or containment vessel and render it inoperable. Similarly, munitions with a large net explosive weight are not suitable for disposal in currently available alternative technologies without size reduction because they exceed the net explosive weight containment capability of the incineration chamber or explosive containment vessel. Note that munitions may be placed in this category due to the large size of their propellant systems as well as their high-explosive main charge.

According to one estimate, OB/OD operations cost $750/ton,[35] while contained disposal operations cost from $2,000/

[29] *Strategic Plan: For the Demilitarization Enterprise*, draft document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 25, 2018.

[30] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

[31] When calculating the 30 percent, rockets and missiles that were demilitarized by static fire were grouped with those open burned.

[32] J.C. King, director for Munitions and Chemical Matters, HQDA, ODASA(ESOH), "DoD Open Burn and Open Detonation (OB/OD)," presentation to the committee, August 22, 2017.

[33] J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, PD Demil, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee, August 22, 2017.

[34] J.C. King, director for Munitions and Chemical Matters, HQDA, ODASA(ESOH), "DoD Open Burn and Open Detonation (OB/OD)," presentation to the committee, August 22, 2017.

[35] This estimate is based on historical data. According to PD Demil, in FY2018 the cost of treating propelling charges by OB was less than $750/ton. J. McFassel, product director for demilitarization, in an e-mail to the committee on September 6, 2018.

ton to $20,000/ton depending on the munition.[36] A 2017 DoD report cited average demilitarization costs including all technologies as $2,890/ton (DoDIG, 2017). The costs of OB/OD and alternatives may be more comparable if the full life cycle costs are considered, including clean closure of the OB or OD facility (see further discussion in Chapter 9). However, based on the data above, the operational costs of alternative technologies could be considerably higher than conducting OB/OD in currently permitted units. Another cost consideration mentioned by the Army is that it may not be cost effective to custom-design a contained disposal technology for small quantities of specific types of munitions or rockets and missiles that are considered unique in some capacity.

Recovery, Recycling, and Reuse

According to information provided by PD Demil, 74 percent of the stockpile munitions demilitarized in FY2015 included a component that was R3.[37] The FY2007 National Defense Authorization Act enabled monies derived from recycling of metals derived from demilitarized munitions to be returned to the demilitarization program to help defray costs. On average, the R3 program collects $5.6 million in proceeds each year.[38] The cost-effectiveness of converting energetics derived from munitions or rockets and missiles into commercial products such as charges for the mining industry, fertilizer, or other useful chemicals depends heavily on current market conditions, which can be highly variable. PD Demil identified this as an obstacle to transferring a greater portion of converted energetics to commercial use and generating more money for the demilitarization program.

Munitions Demilitarized Organically by Alternative Technologies

According to information supplied to the committee by PD Demil, munitions treated by alternative technologies at the organic depots are demilitarized primarily by using meltout or washout to recover the high explosives, or by the ammunition peculiar equipment (APE) 1236 deactivation furnace or APE 1400 rotary kiln incinerator (RKI; for red or white phosphorus munitions). Based on data received from PD Demil from 2012 to 2017, top reasons for choosing alternative technologies at organic facilities include the following:

- Unpredictable results if treated by OB or OD;[39]
- Risk of OB/OD range contamination by chemicals of concern (e.g., depleted uranium, asbestos, white phosphorus);
- Opportunity for R3 for use as donor charges for OD operations;
- Permit limitations on OB/OD net explosive weight; and
- Risk of uncontrolled distribution of munitions or components from excessive kick-outs[40] from the detonation (e.g., some fuzes, submunitions).

Capabilities of the Demilitarization Industrial Base

PD Demil indicates that some 40 to 50 percent of the Army's conventional munitions demilitarization budget is spent at contractor facilities and for contractor activities at Army facilities. Since FY2013, more than 100,000 tons of munitions have been treated under commercial contracts by a small number of contractors (Figure 2.7) using various alternative technologies (discussed in Chapter 4).[41] Although all of these contractors offer the capability to demilitarize entire munitions, including more complex munitions—for example, projectiles and bombs containing submunitions having shaped charges—other contractors offer more specialized and limited services. All of the contained demilitarization systems feature pollution abatement systems that treat exhaust gases.

MATERIALS CONTAINING OR CONTAMINATED WITH ENERGETICS

In addition to munitions in the demilitarization stockpile (B5A account), various types of contaminated nonmunitions waste materials and nonmunitions explosive-contaminated materials at Army facilities must be treated before final disposal due to their possible contamination with propellants, explosives, or pyrotechnics. Nonmunitions waste materials resulting from the disassembly and demilitarization of conventional munitions may include wooden pallets, wooden boxes, metal banding, ammunition links, ammunition cans, cardboard boxes, or plastic sheeting. Nonmunitions explo-

[36] J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, PD Demil, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee on August 22, 2017. Contained demilitarization costs vary greatly from small arms processed in a rotary kiln on the low end, to liquid-fueled missiles having the fuel detanked, treated, and then having the effluents treated as hazardous waste, on the high end. Contained demilitarization costs also involve significantly more labor costs than OB or OD.

[37] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

[38] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

[39] An example would be a situation where burning of a bulk munition may cause a deflagration or detonation of the munition, creating a safety hazard.

[40] The term "kick-out" is not defined in DoD Manual 6055.9-M. However, it is a term commonly used to describe whole or partial munitions or still-active energetics that are ejected from the site of a disposal burn or detonation and that still represent a potential explosive or reactive hazard.

[41] J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee on October 23, 2017.

sive-contaminated materials generated from demilitarization of conventional munitions may include bulk propellant containers, explosive-contaminated coveralls and gloves, metal fragments, cartridge or projectile bodies, and disassembly equipment. Although the majority of contaminated materials generated and treated at the seven demilitarization sites originate from the conventional munitions demilitarization program, at some demilitarization sites explosive-contaminated materials are also generated due to activities that are unrelated to the conventional munitions demilitarization program. All of these waste-contaminated materials are tracked but are not weighed or counted.[42] Hence, the committee was unable to assess the quantity of materials contaminated with propellant, explosives, or pyrotechnics that are being processed at demilitarization stockpile facilities.

Materials that have come in contact with energetics are considered to present an explosive hazard until it has been verified as a material documented as safe. If the Army is unable to certify a material as safe, then it is considered to be a material documented as an explosive hazard. Prior to being released to the public (e.g., as scrap for recycling) or to the Defense Logistic Service Disposition Service sites, this material must be certified as safe through a controlled process consisting of either two, independent, 100 percent visual inspections or treatment designed to remove or destroy any residual explosive or reactive compounds (DoD, 2017c).

Contaminated waste solids are sometimes soaked in fuel oil to facilitate combustion, while contaminated liquids, which may include (but are not limed to) acetone, toluene, hexane, fuel oil, minor amounts of 1,1,1 trichloroethane, cyclohexanone, denatured alcohol, dimethylfloroamide, and methylene chloride, are typically combustible (CAAA, 2016).[43]

Demilitarization sites conduct burns of nonmunitions waste and explosive-contaminated materials, unrelated to the demilitarization program to support installation-wide housecleaning activities. On average, a demilitarization site will conduct burns of energetic-contaminated materials generated from the conventional munitions demilitarization program 5 or 6 days per month.[44]

Material documented as an explosive hazard can be transferred to be handled at both private and government facilities outside the facility where they were generated. This requires compliance with DoD regulations, which include proper documentation of chain of custody, their management and disposition in accordance with federal or state hazardous material and hazardous waste regulations, regulations for transportation, training of personnel that releases the materials, and so on (DoD, 2017c). Receiving facilities require proper permits, facilities, and procedures to handle these materials, as well as trained personnel. Hence, materials contaminated with energetics can also be sent to hazardous waste treatment facilities that satisfy these requirements in lieu of OB.

Finding 2-5. Nonmunitions waste materials, including solvents and other organic liquids, positively identified as pyrotechnic, explosive, or propellant-contaminated are treated via OB at some of the stockpile demilitarization sites.

Recommendation 2-2. The Office of the Product Director for Demilitarization should investigate the use of alternative treatment or disposal methods, including commercial treatment, storage, and disposal facilities, for positively identified pyrotechnic, explosive, or propellant-contaminated nonmunitions wastes.

REFERENCES

CAAA (Crane Army Ammunition Activity). 2016. Open Detonation Detonation/Open Burning Tactical Communication Plan.

CJSCI (Chairman of the Joint Chiefs of Staff Instruction). 2014. 4360.01. Explosives Safety and Munitions Risk Management for Joint Operations Planning, Training, and Execution. http://www.jcs.mil/Portals/36/Documents/Library/Instructions/4360_01.pdf?ver=2016-02-05-175039-810.

DoD (U.S. Department of Defense). 2008. Directive 5160.65. Single Manager for Conventional Ammunition (SMCA). http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/516065p.pdf?ver=2017-11-16-120801-720.

DoD. 2017a. Directive 6055.09E. Explosives Safety Management. http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/605509e_dodd_2016.pdf.

DoD. 2017b. Instruction 6055.16. Explosives Safety Management Program. http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/605516p.pdf?ver=2017-11-14-112331-590.

DoD. 2017c. Instruction 4140.62. Material Potentially Presenting an Explosive Hazard (MPPEH). http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/414062p.pdf?ver=2017-10-18-143048-107.

DoDIG (Office of the Inspector General, U.S. Department of Defense). 2017. DODIG-2018-052. The Army Demilitarization Program. https://media.defense.gov/2017/Dec/21/2001860132/-1/-1/1/DODIG-2018-052.PDF.

GAO (United States Government Accountability Office). 2015. GAO-15-538. Improved Data and Information Sharing Could Aid in DOD's Management of Ammunition Categorized for Disposal. https://www.gao.gov/assets/680/671536.pdf.

Hrycak, O. and T.G. Crank. 2015. Ammunition Demilitarization Research Development Technology and Engineering Program Update. Parsippany, N.J.: 2015 Global Demilitarization Symposium.

Joint Ordnance Commanders Group. 2017. Joint Conventional Ammunition Policies and Procedures (JCAPPs). https://www.dau.mil/cop/ammo/DAU%20Sponsored%20Documents/Joint%20Conventional%20Ammunition%20Policies%20and%20Procedures%20October%202017.pdf.

Mottel, W.J., J.F. Long, and D.E. Morrison. 1995. Industrial Safety is Good Business – The DuPont Story. Hoboken, N.J.: John Wiley & Sons, Inc.

NSC (National Safety Council). 2001. Department of Defense Executive Assessment of Safety and Occupational Health Management Systems. Itasca, Ill.: National Safety Council.

[42] *Handling of Energetics Contaminated Non Munitions Wastes*, document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 9, 2018.

[43] Ibid.

[44] Ibid.

3

Review of Conventional Open Burning/ Open Detonation Technologies

This chapter describes the processes used at the seven stockpile depots for performing munitions demilitarization using open burning (OB) and open detonation (OD) and provides background information on the procedures, hazards, and environmental impacts of OB/OD.

OB/OD has historically been the standard method for disposal of excess, unserviceable, or obsolete military munitions because it is a technically simple method of disposal that is frequently the least expensive and easiest to perform. OB and OD have, however, come under increasing scrutiny and criticism from environmental regulators and public interest groups and local residents for their potential human health and environmental impacts.

COMPONENTS OF ENVIRONMENTAL AND PUBLIC HEALTH CONCERN

An acceptable demilitarization technology would destroy munitions components while producing emissions or effluents that are within regulatory risk ranges. Because complete destruction of energetics or other chemicals of concern is generally not achievable with any technology, trace amounts of substances of potential public health and environmental concern may be released. This is particularly true of OB/OD, where residues such as smoke, soot, and various gases are released directly to the environment. The possibility that human or environmental exposures to those substances might occur has been a source of concern for the Army, the U.S. Environmental Protection Agency (EPA), states, and communities in the vicinity of demilitarization facilities for some time (see Appendix D).

Several classes of substances associated with munitions demilitarization may be of public health or environmental concern. Those include nitramine explosives (RDX, HMX); other nitrosated explosives (e.g., nitroglycerine, TNT); elemental metals (e.g., aluminum, arsenic, cadmium, chromium, copper, cobalt, iron, lead, magnesium, mercury, silver, zinc); volatile and semi-volatile organics (e.g., 2,4-dinitrotoluene, 1,3-butadiene, benzene, methylene chloride, phthalates); polycyclic aromatic hydrocarbons (products of incomplete combustion, e.g., benzo[a]pyrene, benzo[a]anthracene); chlorinated dioxins and furans; and perchlorate (a component of some propellants). Those substances may be released during OB/OD to the air, groundwater, surface water, and soil. Contained systems generally have back-end pollution abatement systems that treat offgases prior to being released, with liquid and solid residues being captured and treated according to the Resource Conservation and Recovery Act (RCRA) permits. Hence, while some of the same contaminants may be generated following treatment with alternative technologies, contained technologies are typically designed to mitigate releases to the environment as prescribed in the facility's RCRA or Clean Air Act (CAA) permits.

A recent study characterized air emissions in the downwind plume following OB/OD activities involving a number of different propellants and munitions (Gullett et al., 2016). Analytes included particulate matter, carbon dioxide, carbon monoxide, methane, volatile organic compounds, chlorine species (HCl, chloride, chlorate, perchlorate), polychlorinated dibenzodioxins and polychlorinated dibenzofurans, and particulate-based metals. Combustion was sometimes incomplete, depending on the munitions treated. That study used an aerostat-lofted instrument package to analyze emissions following actual OB/OD activities at a munitions depot. That study, as well as a following study that sampled OB plumes using sensors mounted on an unmanned aerial vehicle (Aurell and Gullett, 2017), yielded results that were consistent with an earlier study (the "Bang Box" study), which also characterized air emissions from OB/OD of various similar munitions, but did so using instruments inside a confined chamber and small volumes of explosives and propellants (Wilcox et al., 1996).

Substances generated by munitions demilitarization become potential threats to human or environmental health only if exposure occurs, and only if that exposure occurs in a manner likely to produce adverse health effects. The magnitude and character of health effects that a particular demilitarization site or activity poses to installation personnel or the public can be characterized by performing human and environmental health risk assessments, often a requirement of RCRA permitting for OB/OD units. Risk assessments evaluate exposures that might occur directly—via groundwater, surface water, soil, and air—as well as indirectly—such as by consuming contaminated wildlife—and estimate the likelihood that the exposures will result in adverse consequences. The extent to which risk assessment plays a role in establishing permit conditions for OB/OD operations and alternative technologies is discussed in Chapter 6.

OVERVIEW OF OPEN BURNING AND OPEN DETONATION

During both OB and OD the munitions to be demilitarized are destroyed by either burning or detonation, resulting in destruction of the energetics, demilitarization of the munitions, and release of energy in the form of heat, light, and shock. Residues of OB/OD include atmospheric emissions and fragments of the munitions components that are not consumed during the burning or detonation, and result in contaminated soil and sometimes groundwater as well. The munitions may require varying amounts of preparation, including disassembly to separate energetic components or removal of environmentally hazardous components that may not be disposed of by burning or detonation.

Both OB and OD at the Army stockpile depots are performed under RCRA permits issued by EPA or EPA-authorized state agencies. These permits impose a number of restrictions intended to enhance safety and limit impacts to human health and the environment. The following are typical permit restrictions governing the performance of OB and OD:

- Net explosive weight (NEW) limits. The NEW limits can be any combination of (1) the maximum amounts of energetics per burn pan or disposal pit, (2) the total of all burn pans or disposal pits in one burn operation or detonation event, or (3) allowable totals per day or per year. Each RCRA permit has specific NEW restrictions.
- Limits on the number of burns or detonations per day.
- Meteorological limits (e.g., average wind speeds between 3-20 miles per hour, wind direction away from publicly accessible areas, and less than 50 percent chance of precipitation).

More information on permitting is provided in Chapter 6.

Although handling and using energetics and high and low explosives is inherently hazardous, as discussed in Chapter 2, the Office of the Product Director for Demilitarization (PD Demil) has a good safety record for performing OB/OD. According to information provided by the PD Demil[1] there have only been two accidental detonations resulting in two minor injuries and one serious injury during OD operations since 2004.

The following descriptions of OB/OD were developed by reviewing nine Army depot standard operating procedures (SOPs). Note that one SOP for static firing of rocket motors was reviewed,[2] and the committee categorizes static firing of rocket and missile motors as OB because the rocket or missile motor propellant is burned and the products of combustion are directly emitted to the atmosphere.

The SOPs reviewed by the committee are:

- Blue Grass Army Depot (BGAD) SOPs for OB/OD (BGAD, 1996),
- Crane Army Ammunition Activity (CAAA) SOPs for OB/OD (CAAA, 2017a and 2017b),
- Letterkenny Army Depot (LEAD) SOP for OD (Letterkenny Army Depot, 2017),
- McAlester Army Ammunition Plant (MCAAP) SOP for OB (McAlester Army Ammunition Plant, 2017), and
- Tooele Army Depot (TEAD) SOPs for OB, OD, and static firing (Tooele Army Depot, 2017a, 2017b, 2017c).

The operations and procedures summarized in the following sections are not intended to be detailed or all encompassing. Instead, these summaries are intended to provide the reader of this report with (1) a basic understanding of how OB/OD is performed at the depots to help the reader evaluate the challenges and impacts of implementing alternatives to OB/OD at these facilities, addressed in later chapters, and (2) an understanding of variations in the procedures used and in the type and quantity of materials handled and disposed of by OB/OD at the seven Army depots that are the focus of this study.

The committee notes that the SOPs vary significantly in their style and level of detail. For example, the OB SOP for BGAD is 38 pages in length versus 204 pages for the CAAA OB SOP. This is because (1) the type and volume of material being disposed of at the two depots are significantly different, and (2) the depots are authorized to develop and implement their own local procedures in order to comply with their specific RCRA permits and other local requirements as long as they also comply with all DoD and Army technical requirements such as DoD 6055.9-M[3] and Army technical

[1] OB/OD Accident Info, document provided to the committee via e-mail on October 6, 2017, by John McFassel, product director for demilitarization, PEO AMMO.

[2] Static firing of rocket and missile motors is the process of mounting the rocket or missile motor in a fixed position on a special stand and initiating it to allow the propellant to burn while the motor is held in place.

[3] DoD Manuals (6055.9-M, *DoD Ammunition and Explosives Safety Standards* (Volumes 1–8)), https://www.wbdg.org/ffc/dod/manuals.

manuals (DA, 1982). The committee believes that the SOPs provided for review by the Army are typical of those used at the other Army stockpile depots and represent the range of types and volume of OB/OD performed.

Open Burning

"Open Burn" is defined in DoD Manual 6055.9-M, Volume 8, as, "An open-air combustion process by which excess, unserviceable, or obsolete munitions are destroyed to eliminate their inherent explosive hazards" (DoD, 2012). Figures 3.1 and 3.2 show examples of OB operations.

OB is technically appropriate for the disposal of munitions, bulk energetics, and other waste materials that are unlikely to detonate and are more prone to burning when ignited. Examples of such munitions, bulk energetics, and waste materials include the following:

- *Small arms ammunition (SAA)*: The only energetics in SAA are a small, smokeless powder propellant charge, a small primer, and a tracer in some SAA cartridges. These ignite or "cook off" when adequately heated, demilitarizing the SAA. OB of SAA is frequently performed in a containment cage or "popping furnace" or, in the case of CAAA, in "pipe pits." As with all OB, the resulting air emissions are released directly to the atmosphere, and residues, consisting of melted projectiles and brass cases from the burned SAA, are left in the furnace to be periodically removed.
- *Bulk propellants and other nondetonating energetics*: Propellants removed from SAA and larger projectiles, rockets, and missile systems, and bulk propellant from propelling charges are appropriate for OB. They are either removed from the weapons system, spread out on a "burn pan," and remotely ignited or (in the case of rocket and missile motors) can be static fired (Figure 3.3 shows a static fire operation). In both cases, there is very little physical residue from the energetics remaining at the OB site, as most of the energetics is consumed by the burning process. Only small amounts of ash remain after the burn, but, as with all OB, all of the airborne emissions are released directly without treatment to the atmosphere. The ash is removed following each OB event for subsequent disposal, typically as hazardous waste.
- *Bulk explosives*: Some bulk explosives are suitable for disposal by OB because they tend to burn efficiently and not detonate unless they are confined and the detonation is initiated by an adequate explosive initiator, such as a blasting cap. The process for burning bulk explosives is similar to that for OB

FIGURE 3.1 An open burn operation at the Hawthorne Army Ammunition Depot. SOURCE: Joint Munitions Command Public Affairs Office.

FIGURE 3.2 An open burn operation at Letterkenny Munitions Center. SOURCE: Joint Munitions Command Public Affairs Office.

of bulk propellants. The possibility of a high-order detonation during burning exists, so adequate separation distance between the OB site and personnel and structures is required.

- *Waste contaminated with propellant, energetics, and other contaminants*: Some of the depot RCRA permits authorize them to dispose of flammable contaminated material by burning, usually on a bed of scrap such as contaminated wood or other flammable material. In this case the burn is often started and sustained with added fuel oil.

The following general information and description of procedures for OB is based on the OB SOPs reviewed.

The range of material authorized for disposal by burning under the SOPs varies from being limited to only bulk propellant and propelling charges (e.g., at BGAD and TEAD) to the materials that may be burned at CAAA. CAAA is authorized to burn Composition B sludge; Explosive D and Explosive D contaminated material; rocket motors; white phosphorous; scrap red phosphorus and red phosphorus sludge; flare, smoke, and ignition compositions; contaminated waste solids (soaked in fuel oil to enable combustion); and contaminated liquids that are "positively identified as pyrotechnic, explosive, or propellant (PEP) contaminated." These contaminated liquids "include, but are not limited to, acetone, toluene, hexane, fuel oil, minor amounts of 1,1,1 trichloroethane, cyclohexanone, denatured alcohol, dimethylfloroamide, and methylene chloride," and other "contaminated solvents and sludges."

The size and volumes of OB operations range from two burn pans that can be used a maximum of three times each 24-hour period (BGAD), with an estimated daily production rate at BGAD of 15,000 lb of explosives and propellants, to the OB operation at CAAA, which is authorized to burn the range of hazardous material as described above with the maximum per-pan burn limit based on the type of material being burned. The NEW limits at CAAA vary from a low of 25 lb for black powder, pentolite, and PETN to 1,000 lb of Composition B explosive and 1,500 lb wet weight for certain propellants that are shipped wet, such as "large web smokeless powder."[4] The CAAA SOP includes procedures for performing OB in

[4] The CAAA SOP has different NEW limits and procedures for "small web smokeless powder" (defined as propellant used in 3-in. and smaller projectiles) and "large web smokeless powder" (defined as propellant used in projectiles larger than 3-in.).

FIGURE 3.3 Static firing (a form of OB) of Shrike rocket motors at Letterkenny Munitions Center. SOURCE: Joint Munitions Command Public Affairs Office.

- Eighteen steel pans.
- Three steel "sludge burn pans."
- "Incinerator pits" with concrete containment floors and walls with the floor covered with a minimum of 6 in. of sand or a sand and clay mixture.
- Two "pipe pits," which are wood dunnage-fueled systems with a munitions feed system using forced air "fire boxes" for burning small arms, cartridges, primers, tracers, detonators, blasting caps, and other munitions with relatively low NEW.
- An "incendiary cage," which consists of the wood dunnage-fueled burn cage and a conveyor feed system that is used for burning larger flares, pyrotechnic signals, munitions candles, simulators, mortar primers, fuzes, small rocket motors, propellant charges, and other munitions with a greater NEW than is allowed in the "pipe pit." This facility has a sand-covered concrete floor, and the burning can take place directly on the sand-covered concrete floor or in steel boxes placed atop the sand-covered concrete floor, depending on the method of feeding munitions into the system. Burning directly on the sand-covered concrete pad is performed to dispose of material that includes, "but should not be limited to: wood, cardboard, fiberboard, metal parts, plastics, ordnance hardware; projectile bodies, cartridge cases, mine/bomb skins, propellant containers/cans, that have been partially decontaminated by other methods, that is, physically emptied, burned, steam melted, water/chemically desensitized, or that have been visually inspected by qualified personnel, to assure that only minimal explosives are present." Fuel-soaked wooden dunnage is used to fuel burns on the concrete pad.
- A "flashing pad complex" consisting of steel pans or boxes placed inside pits that are used to burn explosives, projectiles, and warheads that have been vented so that the explosives are unconfined.

All of the SOPs limit burning operations to periods of daylight when specific meteorological conditions are met including wind direction and speed, cloud cover, visibility, humidity, and ensuring that conditions are not conducive for lightning strikes.

The SOPs frequently have other restrictions prohibiting burning certain compounds, including hexachloroethane and other riot control agents, white phosphorus, plasticized white phosphorous, and red phosphorous (examples of depots with these restrictions are BGAD and LEAD). Not more than 55 gallons of solvents are specifically authorized for burning per day at MCAA.

The Army depots have consistent procedures for initiating the burns, and two methods of ignition, electric and nonelectric, are authorized for use. Some of the depots specify one type of ignition and others allow both types. Nonelectric ignition consists of a mechanical pull igniter and safety fuse (also known as "time fuse") attached to an ignition charge burn initiator (locally prepared bags of smokeless powder). Electric ignition uses electrically fired "squibs" that are placed in the burn initiator bags and functioned to initiate each burn. In both cases the time fuse or the squibs are placed in locally prepared bags of smokeless powder, which are, in turn, placed and ignited in the burn pan or other apparatus to ignite the material to be burned. Most of the SOPs allow wood dunnage soaked with fuel oil be included in the burn to help ensure ignition.

Most of the SOPs have oversight and quality inspection requirements by "surveillance personnel" or the depot's Quality Assurance Department, but these requirements vary. The SOPs all employ the following general OB procedures:

1. Technicians don the required personal protective equipment for each operation.
2. A specified cooling time of approximately 2 hours must be observed following a previous burn. Some SOPs require taking temperature readings in the pans, while others allow water to be sprayed on the pans as a cooling technique.
3. Usually the burn pans are cleaned of residue from the previous burn with subsequent containerization and disposal.
4. Inspections are made to ensure proper bonding (grounding) of the burn pans.
5. Required local notifications are made to the depot environmental and range managers and approval to initiate the burn is received.

The following procedures are implemented for each burn:

1. The material to be burned is transported to the site and placed or poured into the pan(s). This is sometimes required to be a specific depth (a 3 in. deep layer at BGAD and McAlester Army Ammunition Plant), while other depots specify various depths of material and NEW depending on the type of material being disposed of (CAAA).
2. Most personnel depart, while a minimum number of technicians remain at the burn pans to install the ignition systems in each burn pan.
3. Depending on the type of ignition system used (electric or nonelectric), either the mechanical pull igniters are initiated and the technicians depart the area in a prepositioned safety vehicle to the designated observation point or the technicians depart to the firing point and initiate the electric squib ignitors.

The following procedures are implemented following the burn:

1. Serviceable propellant containers are placed in storage for reuse. Unserviceable propellant containers are inspected, crushed, and removed as scrap.
2. The required wait time is observed following the burn, and water wet-down of the pans may be performed if authorized.
3. After the wait and cooling time the technicians perform an inspection. If there is unburned and "kicked-out"[5] propellant, it is collected for addition to the next burn.
4. Residue from the burn is removed from the pans and placed in drums for disposal as hazardous waste by the depot's environmental division.
5. Various methods for documenting the burns is completed. This varies from completing detailed forms to maintaining a range log book.

Open Detonation

"Open Detonation" is defined in DoD Manual 6055.9-M as, "An open-air process used for the treatment of excess, unserviceable, or obsolete munitions whereby an explosive donor charge initiates the munitions being treated." Figure 3.4 shows an OD operation. Figure 3.5 shows munitions being prepared for venting, which is explosively punching holes in the munitions casing, to expose the filler material and is considered to be OD because it is possible that the venting may cause a high-order detonation. Figure 3.6 shows the results of a venting operation.

Munitions and explosives that are likely to reliably detonate when initiated are technically appropriate for OD. OD is commonly performed by placing the munitions to be demilitarized into a prepared trench or pit, placing donor charges in contact with the munitions, placing prepared detonation initiators on the donor explosives, covering the prepared OD "shot" with soil removed from the trench (a process known as "tamping" designed to decrease the noise, shock, and debris ejected from the detonation), and then initiating the disposal detonation from a distant and protected location. The detonating donor explosives initiate almost immediate "sympathetic detonations" in the munitions, causing the munitions to also detonate, resulting in their demilitarization.

OD generally results in a greater amount of solid residue remaining at the site because there is usually a greater volume of inert components (such as bomb and projectile

[5] The term "kick-out" is not defined in DoD Manual 6055.9-M. However, it is a term commonly used to describe whole or partial munitions or still-active energetics that are ejected from the site of a disposal burn or detonation and that represent a potential explosive or reactive hazard.

FIGURE 3.4 An open detonation at Letterkenny Munitions Center. SOURCE: Joint Munitions Command Public Affairs Office.

FIGURE 3.5 Technicians prepare bombs for venting (a form of OD) at the Crane Army Ammunition Activity. SOURCE: Joint Munitions Command Public Affairs Office.

FIGURE 3.6 Vented bombs at Crane Army Ammunition Activity. SOURCE: Joint Munitions Command Public Affairs Office.

cases) input into the OD process compared to OB. Although the components and heavy steel cases of the munitions are demilitarized, they are not "consumed" by the detonation and are not actually "destroyed." The inert components are shattered into fragments of varying sizes by the detonation, and the fragmented metal components, dispersed by the detonation, remain in the disposal trench and the surrounding area as defined by the fragmentation distance of the detonation. This makes the cleanup of solid residues from OD more time-consuming and costly than cleanup of residues from OB, which are most often confined to a burn pan.

Examples of munitions that are appropriate for OD demilitarization are munitions that are filled with high explosives and are designed to detonate such as projectiles, bombs, grenades, and rocket and missile warheads.

The following description of typical procedures implemented during OD operations is based on the SOPs provided by PD Demil for review. The various Army depot OD SOPs are more similar than those for OB, and the committee believes that the SOPs reviewed are representative of the procedures performed at the seven stockpile depots. The OD SOPs are typically approximately 80 pages in length.

The range maximum NEW limits are described in the SOPs, but they vary based on the size of the detonation facilities and the mission of the depot. For BGAD, OD is limited to doing disposals in 30 disposal pits with a 100 lb NEW for each pit (a maximum total of 3,000 lb per disposal detonation event). There are 6 primary demolition pits at CAAA, and the NEW limit for each pit is 500 lb, with a 70,000 lb NEW maximum allowed on the range. The CAAA range also has one pit designated for the disposal of rocket motors and a secondary range with a maximum NEW limit of 1,000 lb. TEAD has 19 detonation pits on the "TN Range" and 25 on the "TS Range," with up to 3,000 lb NEW authorized for detonation in each pit.

Many of the SOPs contain prohibitions on the detonation of some types of munitions. Disposal by detonation of hexachloroethane and other riot control agents, colored smoke, white phosphorous, red phosphorus, and depleted uranium is specifically prohibited in the BGAD SOP. No prohibited munition types are specified in the CAAA SOP. The LEAD SOP prohibits detonation of "dye filled rocket warheads and Navy armor piercing rounds."

The OD SOPs contain specific weather and environmental conditions that are similar to the restrictions for OB that must exist before initiating a disposal operation. At BGAD each disposal detonation must be approved by a "planning team" that prepares a "daily authorization" for OD operations, and "surveillance personnel" must perform and document safety inspections of OD operations at least daily. The CAAA SOP has less rigid "notification requirements" to be implemented before OD is performed, and there are no specific surveillance or quality requirements, although it is possible that surveillance and quality requirements are contained in a different SOP belonging to those departments.

The type of initiation (electric or nonelectric) varies among the Army depots with some authorized to use both. The various depots also use different donor charges, most likely based on local availability. For example, at TEAD, TNT, Composition B, Composition C, and Bangalore Torpedoes[6] are authorized for use as donor charges. In all cases the donor charges are initiated by detonation cord connected to initiator explosives (usually blocks of Composition 4 or TNT) that, in turn, are placed on the donor explosives.

The SOPs contain the following general procedures that are performed for each detonation shot:

1. Checking continuity in the firing wire and the resistance of the blasting caps (electric initiation) or receiving the nonelectric initiation system components (for nonelectric initiation).
2. Receiving the munitions for OD and the donor charges.
3. Preparing the detonation pits by digging them at least 6 ft. deep using a bulldozer. Some of the SOPs specify different depths of excavation.
4. Placing the munitions for disposal in the prepared pits as specified in detailed SOP requirements.
5. Loading donor explosives on top of and around the disposal munitions.
6. Preparing the electric or nonelectric detonation system. Normally two independent systems for each detonation are used to help avoid misfires and ensure high-order detonations.
7. Placing the prepared initiation charge on the donor charge.
8. Covering the prepared detonation shot with soil using a bulldozer while ensuring that the detonation cord is undamaged and protrudes from the ground. The minimum amount of soil to tamp the shot varies in the SOPs. Above-ground shots are authorized at LEAD, but they are limited to 50 lb NEW and are performed only when the demolition supervisors have determined that above-ground OD is necessary, typically for safety reasons. BGAD specifies covering each shot with at least 6 ft. of soil. An earth cover 15 ft. deep is required at TEAD for shots larger than 50 lb.
9. Connecting the electric or nonelectric blasting caps to the detonating cord leading into each pit.
10. Electric initiation of the detonations from the designated safe area after ensuring that the area is clear of personnel and approval for the detonation has been received. For nonelectric initiation the time fuse igniters are actuated at the disposal pits and the technicians then depart to the safe area.
11. Procedures to be followed in the event of a misfire are included in the SOPs.
12. Upon completion of the detonations the technicians inspect the demolition area and collect large debris and kick-outs. Large debris that does not contain explosives is collected for range maintenance and recycling. That with explosives is added to the next detonation event to achieve disposal.
13. Reporting requirements vary among the SOPs with some requiring formal reports and others using log book entries.

[6] A Bangalore torpedo is a high-explosive-filled steel tube designed for use by soldiers for cutting trenches and clearing minefields.

REFERENCES

Aurell J., and B. Gullett. 2017. Characterization of Air Emissions from Open Burning at the Radford Army Ammunition Plant. https://www.deq.virginia.gov/Portals/0/DEQ/Land/Radford/Radford_Final_Report.pdf?ver=2017-09-27-151820-227.

BGAD (Blue Grass Army Depot). 1996. Standard Operating Procedure BG-0000-H-007 (Revision 9, Change 3), Demilitarization by Open Burning and Standard Operating Procedure BG-0000-G-163 (Revision 10, Change 1), Demilitarization by Detonation. Richmond, Ky.: Blue Grass Army Depot.

CAAA (Crane Army Ammunition Activity). 2017a. Standard Operating Procedure CN-0000-H-003 (Revision 5, Change 1). Destruction by Burning by Various Methods at the Ammunition Burning Grounds or the Demolition Range Explosives Burning/Flashing Pad Complex.

CAAA. 2017b. Standard Operating Procedure CN-0000-G-241 (Revision 6, Change 2), Disposal of Ammunition, Explosives and Other Dangerous Articles (AEDA) By Detonation.

DA (Department of the Army). 1982. TM 9-1300-277. General Instructions for Demilitarization/Disposal of Conventional Munitions. Washington, D.C.: Headquarters, Department of the Army.

DoD (U.S. Department of Defense). 2012. Manual Number 6055.09-M, Volume 8. DoD Ammunition and Explosives Safety Standards: Glossary. https://www.wbdg.org/FFC/DOD/DODMAN/605509-M-V8.pdf.

Gullett, B.K., J. Aurell, and R. Williams. 2016. Characterization of Air Emissions from Open Burning and Open Detonation of Gun Propellants and Ammunition. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=337030.

Letterkenny Army Depot. 2017. Standard Operating Procedure LE-0000-G-014 Revision 8, Change 0. Detonation of Conventional Ammunition, Missile Items and Components at Demolition Ground #2. Chambersburg, Pa.: Letterkenny Army Depot.

McAlester Army Ammunition Plant. 2017. Standard Operating Procedure MC-0000-H-003 Revision 15, Change 2. Burning of Miscellaneous Ammunition of Explosives. McAlester, Okla.: McAlester Army Ammunition Plant.

Tooele Army Depot. 2017a. Standard Operating Procedure TE-0000-H-012 Revision 8. Destruction of Bulk Propellant and Propellant Charges by Burning. Tooele, Utah.: Tooele Army Depot.

Tooele Army Depot. 2017b. Standard Operating Procedure TE-0000-G-010 Revision 14. Detonation of High Explosive (HE) Munitions and Explosive Components. Tooele, Utah.: Tooele Army Depot.

Tooele Army Depot. 2017c. Standard Operating Procedure TE-0000-J-168 Revision 2, Change 1. Static Firing of Rocket Motors and JATOS, all DODICs. Tooele, Utah: Tooele Army Depot.

Wilcox, J.L., B. Entezam, M.J. Molenaar, and T.R. Shreve. 1996. DPG-TR-96-015. Characterization of Emissions Produced by Open Burning/Open Detonation of Complex Munitions. http://www.dtic.mil/dtic/tr/fulltext/u2/a349149.pdf.

4

Review of Candidate Alternative Technologies

INTRODUCTION

Alternative technologies in this study are those that do not involve, and can be used in lieu of, open burning or open detonation (OB/OD). Those reviewed in this chapter are presently used or under development to demilitarize the munitions in the conventional munitions demilitarization stockpile. Some of these technologies, referred to by the Office of the Product Director for Demilitarization (PD Demil) as organic capabilities, have been developed and are being used by the U.S. Army at its seven stockpile installations (see Chapter 2). These include the Army's ammunition peculiar equipment (APE) 1236 rotary kiln incinerator, autoclave meltout of energetic materials (APE 1401 M2), water washout and steam-out to clean the munition bodies, cryofracture for size reduction, and the Army's Super Pull Apart Machine (APE 2271), which pulls apart projectiles that dispense submunitions. PD Demil also uses a variety of munition-specific equipment that has the capability to recover materials for reclamation, recycling, and reuse (R3). These include a spent brass sorter for small arms ammunition (SAA; APE 1412) and metal parts flashing furnaces (APE 2048) to flash residual explosives from munition bodies, allowing the clean metal to be reused. Other technologies are used by PD Demil defense contractors engaged in the business of demilitarizing conventional munitions, munition components, and energetics such as propellant in munition cartridges, bagged propellants, and rocket and missile motors.

The committee received briefings from PD Demil about its organic capabilities, visited the Letterkenny Munitions Center in Pennsylvania to discuss equipment used in the contained burning of rocket and missile motors, and submitted extensive written data requests to PD Demil. Committee meetings, site visits, and other activities are reviewed in Appendix A.

The committee also obtained additional information from several contractors about the alternative technologies that they have developed. These include equipment that performs a single function—for example, abrasive water jet cutting to access and reduce the size of munitions, equipment that has the capability to demilitarize an entire munition in a single processing step, and multifunction facilities and equipment that demilitarize whole munitions and their components in several processing steps. Several contractors gave briefings to the committee about their capabilities and experience, while others provided answers to written questions. Finally, the committee confirmed its understanding of the technologies in this chapter with PD Demil or the appropriate vendors to ensure that the information presented in this chapter is accurate.

The organizations providing information to the committee are listed below. Some of these organizations have additional munitions demilitarization capabilities; however, these are the primary ones that the committee has considered.

- *Dynasafe*: Static Detonation Chamber (SDC)-contained burn of munitions;
- *Expal U.S.A.*: Robotic munitions disassembly; use of SDCs for munitions demilitarization;
- *El Dorado Engineering*: Contained burn of energetics, rotary kiln explosive waste incinerator, flashing furnace;
- *General Atomics*: Size reduction using cryofracture, propellant destruction using industrial supercritical water oxidation (iSCWO);
- *General Dynamics*: Automated munitions demilitarization facility, Rotary Kiln Incinerator (RKI), rocket and missile motor segmentation and thermal treatment process, cluster grenade thermal treatment process, nitrocellulose propellant thermal treatment system;
- *Gradient Technology*: Abrasive water jet cutting;
- *MuniRem*: Energetics neutralization; and
- *U.S. Demil*: Decineration process.

The committee also reviewed several studies in which alternative, non-OB/OD technologies are described, reviewed, and in some cases, compared to each other and to OB/OD with respect to various criteria. These studies were carried out over the past 30 years by various organizations and government agencies. They are listed in the references to this chapter. In several of the reviewed studies, alternative technologies are grouped with respect to their role in the munitions demilitarization process. Typical technology groupings include munitions pretreatment and disassembly, energetics removal, munition or energetics destruction, pollution abatement, and resource recovery and recycling.

While the committee did not contact every commercial vendor involved in the demilitarization of conventional munitions, the committee believes that it has examined and discussed existing capabilities with the primary commercial providers currently engaged in this activity.

In the technology review conducted in this chapter, both those technologies that are capable of demilitarizing munitions in a single processing step and those that partially process the munitions are described. This is only a partial compilation; numerous other treatment processes exist and have been evaluated in several of the reports listed in the references to this chapter—for example, Poulin (2010) and Wilkerson (2006). However, the technologies described below are those that have been demonstrated or permitted in the United States (where permits were required) and, in general, have a greater level of maturity than other technologies.

The distinction between technologies capable of demilitarizing whole munitions and those that do partial munition processing is somewhat arbitrary; a technology that is capable of processing an entire munition of one type may require one or more preprocessing steps prior to demilitarization for a munition of another type—for example, a larger or more complex munition.

In this report, candidate alternative technologies that have the potential to demilitarize an entire munition are grouped as follows:

- Contained detonation (CD), where an entire munition is demilitarized/destroyed in an enclosed chamber with an associated pollution abatement system; and
- Contained burn (CB), where a munition is thermally treated in an enclosed chamber, typically an incinerator or a furnace combined with a pollution abatement system.

Several of the technologies described have dual capabilities in that they can perform the contained burning of munition energetics and propellants but also have explosive containment capabilities; thus, they can function as contained detonation chambers as well. Where these capabilities exist, they are so noted.

For many munitions it is not feasible to demilitarize the whole munition using a single alternative technology due to technical, safety, environmental, or cost issues. Examples of such munitions include large bombs, complex cartridges containing submunitions such as grenades and bomblets, and munitions containing shaped charges that could damage containment chambers. Where this is the case, technologies that perform a partial function—for example, those that only reduce munition size or only remove energetic materials—are reviewed with respect to their more limited capabilities while recognizing that a combination of these technologies (in a treatment train) would be needed to demilitarize whole munitions. Thus, the distinction between whole and partial munitions processing depends on the size and complexity of the munition involved. The same contained detonation chamber that can entirely demilitarize a small munition may require a step to modify the energetics (e.g., cutting the energetics to disrupt a shaped charge) for a larger or more complex munition.[1]

All of the technologies that destroy energetic materials using thermal processes have associated pollution abatement systems (PAS) that treat offgases. These treatment processes contain scrubbers, cyclones, baghouses, filters, and other components as needed. They were evaluated as part of the technologies with which they are associated. In addition, nearly all of the technologies will produce secondary wastes, including waste water from water jet cutting, waste/ash particles that may be characterized as hazardous waste, or spent filter materials. These are noted as part of the technology description.

Several of the technologies have the capability to produce materials that can be reclaimed, recycled, or reused (R3). Technologies that have R3 capabilities include the SDC, Decineration, deactivation furnaces, autoclave meltout and water washout to recover energetics for alternative uses, and the metal parts flashing furnace to decontaminate metal parts. These capabilities can result in a revenue stream that partially offsets the costs of using alternative technologies and contributes to the Army's goal of reducing dependence on OB/OD. Where an R3 capability exists, it is noted as part of the technology description.

The technology reviews include a basic description of the technology and, where the information is available, the following:

- A summary of throughput capacity, taking into account physical feed size limitations, explosion containment limitations imposed by U.S. Department of Defense Explosives Safety Board (DDESB) or

[1] Munition size can refer to physical dimensions; larger size munitions may require size reduction in order to be fed into a contained detonation or contained burn chamber. It can also refer to the explosive content of the munition; in terms of its net explosive weight (NEW), measured in TNT-equivalent pounds of explosive. All contained destruction chambers will have a maximum permitted (by Environmental Protection Agency [EPA]-authorized state agency) and approved (by Department of Defense Explosives Safety Board [DDESB]) NEW limitation.

environmental permits, need for munitions pretreatment, munition-specific limitations, munitions and energetics that the technology has processed to date, and average and maximum throughputs achieved to date, especially when processing those munitions that currently are being treated via OB/OD;
- Environmental impacts, including effluents produced and waste stream management processes used to monitor, treat, and, where applicable, recycle effluents for further treatment and to recover, recycle, or reuse processing by-products;
- Health and safety risks to workers and to the public; and
- A qualitative assessment of costs. In general, cost estimates provided here refer to cost/ton of munitions, not life cycle costs.

The quality and detail of the information the committee received in each of these areas varied widely, from in-depth technical information to cursory replies. In some instances, the committee did not receive any information in one or more of the areas for a given technology. This was either because it was nonpublic information (e.g., proprietary) or because the committee simply did not receive the requested information. In such instances, the committee notes below that "information was not made available to the committee." Because of these limitations, it is not possible for the committee to conduct direct comparisons of all aspects of all technologies.

Additional information, where available, includes the following:

- Technical maturity of the technology;
- Permitting status, including throughput and other limitations imposed by permits;
- Ability of the technology to process a variety of munitions, defined by the Army as the omnivorous capability;[2]
- Where capabilities for existing units are limited, the potential to modify the technology to expand its capabilities;
- The potential for monitoring emissions and for recycling effluents for further treatment; and
- Resource requirements to operate the technology.

The technologies reviewed in the "Thermal Decontamination of Munitions Scrap" section have been tested and demonstrated by the PD Demil and its contractors. In the "Emerging Technologies" section, several technologies that are under research and development are reviewed.

PREPARATION TECHNOLOGIES

Prior to the destruction of munition energetic components in contained chambers, a variety of processing steps may be required. These include but may not be limited to munitions disassembly, size reduction to reduce the physical size and net explosive weight of the munitions, and removal of energetic components from the munition. Commonly used processing steps that are used by PD Demil and its contractors are described below.

Disassembly and Size Reduction

This step consists of separating munitions components and size-reducing the components to achieve the maximum net explosive weight (NEW) limit requirements of the treatment technology being used and to expose the energetics within the munition to enable the munition components to be further treated. Processes currently in use are

- Manual and automated disassembly (U.S. Army and its contractors, various locations);
- Cryofracture (at McAlester Army Ammunition Plant [MCAAP]);
- Water jet or slurry jet cutting for size reduction (at Crane Army Ammunition Activity [CAAA] and at Hawthorne Army Depot [HWAD]); and
- Mechanical cutting—for example, band saws.

Manual and Automated Disassembly

Some munitions can be disassembled prior to removal and treatment of explosive components, either manually or robotically. Manual disassembly is slow and presents risks to workers, as they must handle the munitions. Automated disassembly with less worker exposure to the munitions is carried out on processing lines at some contractor facilities where complex munitions—for example, cluster bomb units—are taken apart to expose the submunitions within and where the submunitions are also disassembled to expose explosive materials such as shaped charges. These operations incur periodic accidental detonations, and, when these occur, replacement equipment is needed. For example, the unintended detonation rates during the demilitarization of grenades from cluster munitions at a General Dynamics facility in Missouri has been 1 in 10.7 million grenades, all behind safety walls.[3]

Cryofracture

This process is used to cool ferrous munition bodies below their embrittlement (nil-ductility) temperature, allow-

[2] J. McFassel, product director for Demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee on August 23, 2017.

[3] General Dynamics response to committee questions, May 2018. 160,000,000 grenades from dual-purpose improved conventional munitions and from multiple launch rocket systems with 15 grenade detonations.

ing the munitions to be fractured in a hydraulic press. This allows access to the energetics so they can be treated by thermal destruction. Cryofracture by itself does not destroy energetics. In a typical operation, munitions are transferred into a liquid nitrogen bath by an overhead robot, for between 10 and 45 minutes to cool them to –320°F (–195°C; depending on the size of the munition), removed from the bath by a material transfer robot, placed in a hydraulic press, and compressed until fracture occurs. The munitions debris is then fed to a thermal treatment process such as the APE 1236 rotary kiln incinerator for energetics destruction.

Cryofracture can be used on munitions that require a size reduction processing step and are difficult or costly to disassemble or will cause damage if they detonate during thermal treatment. It has been successfully used on munitions such as 8 inch, 155 mm, and 105 mm projectiles; M23 landmines; M55 rocket motors; 4.2 in. mortars; and various grenades, bomblets, cartridges, fuzes, and bursters. It has been used to access M42 and M46 grenades in the 155 mm high-explosive, dual-purpose projectile (Department of Defense Identification Code [DODIC] D563) in the conventional munitions stockpile.[4]

The U.S. Army Research, Development and Engineering Command has processed more than 67,000 live Artillery Delivered Antipersonnel mines using cryofracture in conjunction with the APE 1236, and a cryofracture unit is currently being used at the McAlester Army Ammunition Plant for cooling and crushing submunitions removed from projectiles (DODIC D501/D502) prior to feeding the munition fragments to an APE 1236 rotary kiln incinerator. Although the U.S. Army Research, Development and Engineering Command has demonstrated a "mobile" cryofracture unit, this unit is now in storage at Crane Army Ammunition Activity but is planned to be placed into service in 2020 to destroy Rockeye bomblets. An advantage of cryofracture is that it allows access to energetics in a munition more quickly than using other methods such as a band saw or a water jet.[5] Potential disadvantages are that nonferrous materials that do not fracture and some internal munition components present challenges. Also, incomplete crushing occasionally occurs, with resulting incomplete deactivation of munitions (e.g., mines) in the APE 1236 rotary kiln incinerator. When this occurs, energetic-contaminated materials are processed through the kiln a second time.[6]

Throughput Capacity

Processing rates will depend on the munition size, the internal arrangement of the munition, and the amount of energetics in the munition. For example, Artillery Delivered Antipersonnel mines can be processed at a rate of 6 mines per minute,[7] for Rockeye bomblets the rate is 7 munitions per minute, and for M42 submunitions the process rate is 42 items per minute.

Environmental Impacts

Cryofracture is a preprocessing step prior to destruction in an APE 1236 or another CB chamber. Permitting constraints regarding emissions and throughputs for the APE 1236 govern the process.

Personnel Safety

Cryofracture is generally conducted remotely by robots behind blast walls to avoid human exposure to safety hazards. If a detonation were to occur while a munition is being processed in the press, the currently used system can withstand a detonation of up to 5 lb NEW. Safety considerations make it most suitable for munitions without a detonator train near the stress points exerted by the cryofracture tooling.

Cost

Information was not made available to the committee.

Waterjet and Slurry Jet Cutting

Waterjets are used both to access munitions by cutting the munitions open to expose the energetics inside and to remove energetics washout. Waterjets use a high-velocity stream of fluid forced through an orifice to form a jet. The fluid is typically water, but other fluids can be used. Abrasives can be added to the stream in the form of a premix slurry or by entrainment at the nozzle to increase the cutting action. While the water can often be recovered and reused, eventually it must be treated as explosives-contaminated wastewater (pink water) and undergo proper treatment before disposal.

Waterjets have been used since the 1920s to wash out high explosives (HE) from munitions. High-pressure waterjets with added abrasives have been used since 1991 to cut HE munitions. Low-pressure jets were used in the 1950s for the U.S. Army's Ammunition and Explosive washout and reclamation system. Low-pressure jets were used to reclaim missile motors in 1953 and for the Hawthorne Army Depot (HWAD) washout system in 1979.

High-pressure jets were installed at CAAA in 2000. More than 250,000 large caliber 3-inch, 5-inch, 6-inch, and 8-inch projectiles have been cut and washed out at CAAA since 2001. This same system is currently being modified to cut the 16-inch Armor Piercing and High Capacity Navy Gun

[4] Cryofracture Munition Experience Database, p. 1. Information provided to the committee by General Atomics, January 2018.

[5] McAlester Army Ammunition Plant response to committee questions, April 2018.

[6] Ibid.

[7] PD Demil table, "Demonstrated Ammunition Demilitarization Technologies," provided to the committee, August 2017.

projectiles containing explosive D filler (ammonium picrate). The goal is to recover 99 percent of the explosive filler and all of the munition metallic scrap.[8]

Although waterjets are inherently dangerous systems,[9] with numerous people injured or killed from commercial pressure washers and cleaning systems, there are only two known munitions-related accidents that have been reported to the committee, and these appear to be unrelated to the use of the waterjet itself. The danger of high pressure can be mitigated by the use of robotics and remote operations. Although waterjets can initiate a detonation of high explosives, this has only occurred with an experimental water jet that used explosives to accelerate the stream beyond the capacity of mechanical pumps. This is highly unlikely to occur in practice.[10]

Compared to band saw cutting, water-jetting is higher in capital cost, not as energy efficient, slower, and less accurate. However, it can cut almost anything, never dulls, and can cut in almost any direction. Waterjets are also less likely to cause an accidental detonation because they do not create a "heat affected zone" in the cut area, as temperatures typically do not exceed 100ºC.

Mechanical Cutting

Mechanical saws—for example, band saws—have been used to cut munitions to reduce their size and to access the HE for washout or other treatment. A band saw has been installed at the Letterkenny Rocket and Missile Disposal Facility for cutting the rocket and missile rocket motors.

Band saws have an inherent safety issue with the heat, shock, and friction of the blade cutting through the munition casing resulting in a potential initiation influence for HE or rocket and missile propellant. This is mitigated in some cases by inundating the cut with water or liquid lubricant or performing the cutting under water. Even though these mitigation techniques are successful enough to achieve DDESB approval, sawing is done remotely with no personnel present to be injured by a potential detonation. In the case of the Letterkenny facility, the committee was told that managers of the facility expect sawing to cause infrequent autoignition of rocket and missile motors, and they are prepared to periodically replace damaged equipment.

Energetics Removal

Once the energetics and other internal components of a munition are accessed, the energetics may be removed using a variety of processes. Two being used by the Army that the committee evaluated are:

- Water washout with water jets as noted above (U.S. Army at HWAD, CAAA); and
- Autoclave meltout (U.S. Army at MCAPP, HWAD).

Water Washout

High-pressure washout (55,000-60,000 psig) of munitions using a waterjet has been demonstrated at HWAD where a low-pressure (5,000-10,000 psig) washout facility was upgraded to a higher pressure in order to reduce water consumption from 10-30 gpm to 0.5-1.0 gpm. These systems are similar to the waterjet cutting systems described above. Energetic fills have been washed out of 105 mm, 120 mm, 165 mm, and 81 mm projectile rounds.

Autoclave Meltout

Once the high explosives are accessed and exposed—for example, by removing the nose plug of a projectile—they can be placed in an Army APE 1401M2 autoclave and heated. Munitions are placed on a carousel and their exteriors are steam heated to drain meltable explosives, which are then collected in a melt kettle. The cycle time per munitions load is about 60 minutes, and the average explosive load is 100-200 lb per hour. The system has been used to remove or reclaim explosives such as TNT from projectiles and bombs. It may also be possible to remove other explosives that can be melted, such as composition B, following pilot testing.[11]

Other Methods

Other methods that have been proposed include washout with ammonia or liquid nitrogen, steamout of energetics, ablation of energetics using solid carbon dioxide pellets, microwave meltout, meltout using an induced current, and laser machining. None of these, however, have been demonstrated on a production scale. Although recovered explosives may be reused in munitions or recycled into commercial products if a market exists, they are more often used as donor explosives in OD operations.

CONTAINED DETONATION CHAMBERS

CD chambers are a technology alternative to the OD of munitions and munition components. These technologies and their associated pollution abatement equipment are intended to demilitarize an entire munition in a single processing step if the munition size and NEW are within the capacity of the equipment. Otherwise, one or more preprocessing steps will

[8] PD Demil, "Status Update on Navy Gun 16 inch Projectile Waterjet Cutting," April 2018.

[9] "Abrasive Waterjet Cutting of Large Munitions." Briefing to committee members by Paul Miller, Gradient Technology, October 2017, p. 23: personnel safety.

[10] Worsey and Summers (1984).

[11] "Demonstrated Ammunition Demilitarization Technologies." Spreadsheet provided to the committee by PD Demil, August 2017.

be required. Because they do not use a "controlled flame device,"[12] CD facilities are permitted as Resource Conservation and Recovery Act (RCRA) Subpart X miscellaneous treatment units rather than as incinerators.[13] In some cases, a Clean Air Act (CAA) permit may be required.

Munitions are prepared for detonation by attaching detonators and donor explosives and then placing in the chamber; the chamber is sealed; and the munitions are detonated. All of the explosive wastes such as offgases, dust, and metal fragments are contained within the chamber or a post-chamber expansion vessel following the detonation. Treated waste material can be tested, and if need be, unreacted energetics can be reprocessed prior to release. Although conceptually feasible as a replacement for OD, these chambers have several limitations, including (1) limited throughput resulting from the need to prepare munitions, load them into the chambers, and periodically clean debris following detonations; (2) the need to withstand repeated shocks resulting from detonations with consequent wear and tear on the pressure vessels; and (3) the donor charge being included in the maximum NEW allowed per load.

The committee reviewed three chambers having contained detonation capabilities, all of which have been used to demilitarize conventional munitions, have been approved by DDESB for specific situations, and have received RCRA permits. The committee also considers another technology, the SDC, to be a contained detonation system. Since this technology also has contained burn capabilities, it is discussed separately in the section "Contained Burn Chambers."

Controlled Detonation Chamber (CDC)

Te CDC originally applied "to replace OD operations for destruction of conventional high-explosive munitions."[14] The CDC is a rectangular cross section detonation chamber providing a contained environment that prevents the release of blast fragments, heavy metals, and energetic by-products. The model D-100 chamber has internal dimensions of 14 ft. wide by 16 ft. high by 20 ft. long and is connected to a cylindrical steel expansion tank 10 ft. in diameter and 71 ft. long. Offgases are directed to the expansion tank, which moderates the pressure wave from the detonation of explosives, and are then processed through a pollution abatement system that consists of a reactive bed filter to remove acid gases, a porous ceramic filter to collect particulates, including soot and dust, and a catalytic oxidizer operating at 1095°C. Two D-100 models have been used at the Milan Army Ammunition Plant, Tennessee, for the destruction of 25,000 155 mm projectiles packed with submunition grenades, and another model, the D-200, has been used to destroy multiple conventional munitions at the Army's CAAA, located at the Crane Naval Surface Warfare Activity in Indiana.[15]

Munitions with a donor charge are mounted in the detonation chamber, the floor of which can be covered with pea gravel to absorb blast energy. Water-filled bags are also sometimes suspended near the munition to help absorb blast energy and reduce fragmentation effects. After the detonation chamber is loaded, its entry port is sealed and the exit from the expansion chamber is also closed. Following a detonation, gases are vented to the pollution abatement system. Offgas monitoring can be carried out to ensure that regulatory limits are not exceeded before release.

The NEW rating for the CDC model TC-60 was 40 lb TNT-equivalent for the destruction of WW I phosgene-filled munitions at Schofield Barracks in Hawai`i in 2008.[16] The NEW rating for the larger D-100 installed at the Blue Grass Army Depot in Kentucky was 49.3 lb.[17] This rating includes the NEW content of the donor charge as well as the munition being destroyed. A D-100 used at Milan had an estimated NEW of 100 lb and a larger D-200 at Crane had a safe NEW, based on testing, of 116 lb.[18]

Based on the explosive safety design review for the CDC conducted by the DDESB,[19] "the minimum donor explosive weight shall be 1-part donor explosive to 1-part energetic fill (1:1) for a munition with energetic fill only; 2:1 for propellant fills; and 3:1 for smoke, riot agent or incendiary fills." However, for the D-200 at CAAA, the NEW of the munition being treated was about three times the NEW of the donor charge,[20] allowing a larger ratio of munition to donor charge than the 1:1 ratio allowed by DDESB for the smaller CDC units.

As of early 2018, PD Demil planned to conduct tests of the larger CDC D-100 at BGAD on 175 2.75-in. and 5-in. rocket motors that would otherwise be open detonated (DODIC J147, J106, J143). Subject to test results and Kentucky state permit requirements, this unit could be used to demilitarize these munitions, which would provide the ability for PD Demil to demilitarize rocket and missile motors with double-based propellant.[21] As of September 30, 2017, these 175 rockets accounted for 1,457 tons in the conventional munitions stockpile. The larger D-200 at CAAA has demilitarized a variety of munitions, including 105 mm cartridges, fuzes, and 155 mm M107 HE projectiles (DODIC D544) that would otherwise be open detonated.

[12] A controlled flame device uses an open flame in the thermal treatment chamber and is regulated as an incinerator under RCRA.

[13] RCRA Permit Policy Compendium: Volume 9: 9486.1987-9498.1996: "TSDF Technical Requirements" (Parts 264 and 265) and "Standards for Managing Specific Hazardous Wastes" (Part 266), https://tinyurl.com/ybk6nwym.

[14] NRC, 2006, p. 30

[15] NRC, 2009, p. 36.

[16] NRC, 2009, p. 30.

[17] NRC, 2009, p. 35.

[18] PD Demil, response to committee questions, April 2018.

[19] DDESB, 2008.

[20] PD Demil, response to committee questions, April 2018.

[21] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization by Open Burning and Open Detonation," presentation to the committee on December 11, 2017.

Throughput Capacity

Processing rates vary with the munitions being demilitarized. Estimated throughput rates vary from 22 per 10-hour day for a 155 mm MK II projectile to 60 per 10-hour day for a M139 bomblet. Typical cycle times, including loading and cleanup, are expected to be 30-45 minutes with 1-3 munitions placed in the chamber per cycle. In a table provided to the committee by the PD Demil,[22] the Army's comment on smaller versions of the CDC (up to model T-60) indicated that this "system is intended for emergency use and not a production environment."

Environmental Impacts

The CDC at CAAA was operated as an RCRA Subpart X unit and experience has been that it can be operated without noticeable noise or vibration problems. Primary wastes produced by the CDC include munition fragments, pea gravel and dust, and lime from the reactive bed filter. Metal munition fragments may be sold for scrap.

Personnel Safety

Manual operation of the CDC includes routine munition preparation operations, placing initiating charges and initiators on the munitions, and mechanically moving munitions into the detonation chamber. Between shots, workers have to reach inside the detonation chamber door to plug in and unplug electrical connectors. Workers can be exposed to hot metal surfaces and to pea gravel dust when cleaning the detonation chamber.

Cost

Although quantitative cost information is not publicly available, an earlier evaluation of the CDC stated, "extensive U.S. experience with destruction of conventional and agent-like munitions indicates that the basic CDC technology is cost effective for destroying projectiles and other types of explosive-containing munitions in a U.S. context."[23] Agent-like refers to munitions containing chemical agents as well as smoke and dye-filled munitions.

In one specific instance, a CDC model D-100 at the Bluegrass Army Depot in Kentucky has been released to the Army by the CDC vendor (CH2M Hill) and is currently Army owned and operated. Thus, there would be no additional acquisition costs for this unit, and operating costs may be reduced when compared with contractor operation, since labor costs (Army versus contractor personnel) should be lower and the Army is not trying to operate the CDC at a profit.

[22] "Demonstrated Ammunition Demilitarization Technologies." Spreadsheet provided to the committee by PD Demil, August 2017.

[23] NRC, 2006, p. 35.

Explosive Destruction System (EDS)

The EDS is a technology having modest CD capabilities. Designed by the Army's Recovered Chemical Munitions Directorate and built by Sandia National Laboratory for the destruction of recovered and reject chemical munitions, the EDS model P2 is a truck-mounted, transportable unit that provides a capability to destroy small quantities of chemical and potentially conventional munitions that fall within its 9 lb NEW limitation. The EDS consists of a sealed cylindrical containment vessel having an inner volume of 20.3 cu. ft. Its inner diameter is 28 in., its inner length is 57 in., and its wall thickness is 3.6 in.

Munitions are placed in a munitions holder, initiating explosives are attached to the munitions, electrical connectors are attached to the charges, and operators slide the holder into the vessel. The vessel door is then closed and sealed. Following leak tests, the operators then remotely detonate the charges. For chemical munitions, neutralization chemicals are then added and mixed with the chemical fill. This processing step would not be needed for conventional munitions.

Throughput Capacity

In terms of physical capacity, the EDS is capable of receiving projectiles up to 155 mm in size. However, its 9 lb NEW capacity, including that of the initiator charge, limits its usefulness for processing the high-explosive 155 mm projectiles in the conventional munitions stockpile, some of which contain shaped charges that can damage the explosive containment vessel and others that have NEWs in the 14-16 lb range. Because the EDS has not been tested with conventional HE munitions, processing rates for these munitions can only be estimated. The cycle time for preparing conventional munitions, loading them into the vessel, sealing the vessel, detonating the munitions, allowing the vessel to cool, opening the vessel, and removing metal and other fragments will vary with munitions but should be in the order of 1 to 2 hours. Multiple munitions can be placed in the EDS as long as the maximum 9 lb NEW is not exceeded.

Environmental Impacts

The EDS has been operated under RCRA permits at several locations in the United States and has destroyed more than 2,600 chemical munitions. When processing chemical munitions, the primary waste produced is 8-10 gallons of hydrolysate per cycle. Although this will not be the case when processing conventional munitions, solid wastes from munitions destruction will be present, including munition bodies and internal components, the constituents of which will vary with the munition processed. Small quantities of aqueous wastes, resulting from periodically washing the EDS vessel with detergent, are also produced.

The waste streams will vary with the munition processed, and these would have to be characterized in order to develop appropriate disposal and post-treatment procedures and before shipment of solid and liquid wastes to commercial treatment, storage, and disposal facilities, as has been done with waste materials from chemical munitions processing.

Personnel Safety

The EDS requires several manual processing operations: placing initiation charges on the munitions; placing a fragmentation shield over the munitions to reduce damage to the vessel walls; making electrical connections; opening, closing, and securing the vessel door; removing debris following a detonation; and cleaning and inspecting the vessel for a subsequent detonation. Operating and maintenance procedures are well developed, and this equipment has been routinely operated as noted above.

Cost

The EDS was designed for occasional use in demilitarizing small numbers of chemical munitions and not for continuous use in demilitarizing conventional munitions. Continuous use could reduce its economic life, since the number of cycles for which it is designed will be reached in a shorter time period than when used intermittently. Because cost data are not publicly available, it is not possible to directly compare the EDS unit costs with those of open detonation or alternative technologies. In addition, all the experience with the EDS is with chemical munitions; hence, any cost data would not be comparable to the demilitarization of conventional munitions.

The committee believes that the EDS is an extremely capable munitions demilitarization system. However, the committee has determined that its applicability to demilitarization of the conventional munitions stockpile is very limited because it is designed for the demilitarization of chemical munitions that contain relatively small amounts of explosives. Although the EDS has extensive capabilities for the neutralization of chemical agents, this capability is not needed for the demilitarization of conventional munitions. Because of the specific design of the EDS, its throughput is too low for it to have anything other than a limited, small-quantity role for the demilitarization of conventional munitions. For these reasons, the committee is not conducting further evaluation of the EDS in this report.

Detonation of Ammunition in a Vacuum Integrated Chamber (DAVINCH)

The DAVINCH is a CD chamber that has been developed by the Japanese firm Kobe Steel for the destruction of recovered Japanese World War II chemical munitions. DAVINCH uses a donor charge placed on munitions to initiate the demilitarization process. The DAVINCH detonation chamber, however, is considerably larger that either the CDC or the EDS. One model (DV-45), used in Japan, has an interior volume of about 652 ft.^{3} (18.6 m^3). A larger unit, the DV-60, has an interior volume of about 1,074 ft.^{3} (30.4 m^3). The explosion containment capacities of the DAVINCH units are reflected in the model numbers: 99 lb (45 kg) NEW for the DV-45 and 132 lb (60 kg) NEW for the DV-60. The physical size of the DAVINCH technology is correspondingly greater than the CDC or the EDS; the DV-45 weighs about 75 tons. A smaller, truck-transportable version called DAVINCH lite is also available. This unit weighs 45 tons, has an outer diameter of 6.9 ft. (2.1 m), and is 23 ft. (7 m) long. DAVINCH lite has been tested with 75 mm and 155 mm projectiles at the U.S. Army Edgewood Chemical Biological Center in Maryland for chemical munition destruction, has been approved by DDESB for a NEW of 52.8 lb (24 kg), and operated under a RCRA Subpart X permit.

The DAVINCH is a double-walled steel chamber with a replaceable inner vessel made of armor steel and an outer vessel composed of multilayered carbon steel plates with the vessels separated by air. After connecting the detonator wires to an initiating charge placed on the munitions, the airtight circular DAVINCH door is closed remotely. Air is then evacuated from the inner vessel until a pressure of 0.2 pound per square inch (psia) is reached. Either an electric delay detonator or instantaneous electric detonators then sequentially detonates the suspended munitions to reduce the maximum pressure on the inner vessel walls. Under a near-vacuum, the munitions are detonated and implode, reducing noise. Fragment velocity and vibration are also reduced, extending the life of the inner vessel. Detonation in a near-vacuum also reduces the volume of offgas produced. The chamber is sealed and isolated from the offgas treatment system during the detonation process; consequently, an expansion chamber is not required.

The offgases are then removed from the inner vessel by a vacuum pump. Post-processing treatment for conventional munitions consists of filtering the offgases and passing them through a small diverging electrode plasma arc reactor having an arc temperature of 1,600°C to thermally treat (oxidize) the offgas, primarily H_2 and CO, followed by quenching and scrubbing of the offgases. Treated gases are then held in a retention tank and tested. If need be, the offgas can be recirculated through the plasma arc reactor for further treatment before being released to the atmosphere; thus, the DAVINCH has a hold-test-release capability.

Throughput Capacity

The throughput rate for processing munitions in the DAVINCH will depend on the size of the vessel used (a longer vessel will be able to process a greater number of munitions per cycle), the vessel's NEW limitation, the ratio of donor charge NEW to munition NEW, and the cycle time per munition load. The only use of DAVINCH for demilitarizing conventional munitions was the use of a DAVINCH model DV-50 at Poelkapelle, Belgium. In this application, packages of 7.7 cm, 10.5 cm, and 15 cm projectiles were destroyed along with about 50 World War 1 21 cm projectiles.[24] The processing rate for the 21 cm projectiles was one munition per cycle at a rate of 3 to 4 cycles per day. After 1,700 shots (cycles), including 360 cycles in which conventional munitions were destroyed, the technology vendor stated that "fragments from those large conventional shells damaged the inner chamber, resulting [in] the decrease of wall thickness at the proximity of the ammunition mounting position."[25] As a result, a new inner chamber was fabricated and installed.

The ratio of donor charge to munition NEW that would be used varies with the type of munition, the number of munitions per cycle, and whether detonations are initiated by the donor charge or by other munitions in a bundle. At Poelkapelle, Belgium, the donor to munition charge ratio varied from 0.4 to 3.0. The higher quantities of donor charge, relative to the munition NEW, was needed for some munitions to reduce the size and velocity of the fragments produced, thus reducing wear on the inner chamber walls and extending the chamber's useful life.[26]

Environmental Impacts

DAVINCH produces four waste streams: gases resulting from detonations, munition fragments, small quantities of liquid from the offgas scrubber, and liquids following cleaning of the vessel. The gases can be stored in a retention tank for testing and recirculated through the plasma arc unit for further treatment, if necessary, prior to release to the atmosphere. Although munitions residue and fragments will consist mostly of munition bodies, the internal constituents of the munitions are expected to vary and could contain heavy metals, melted plastics, and other materials that could require additional treatment or separation before recycling the munition bodies.

Personnel Safety

Unless a robotic arm is used, operations for DAVINCH are manual, involving munition handling, placing initiating explosives and initiators on the munitions, and insertion of munitions into the chamber. These operations involve direct worker exposure to the munitions and to the initiation explosives during munitions preparation and loading. Following a detonation, munition fragments are removed remotely.

Cost

Due to its size, the capital and operating costs for DAVINCH may be higher than for other detonation chambers. In Poelkapelle, Belgium, where both chemical and conventional projectiles were processed, eight workers carried out three destruction cycles per day. As is the case with other private sector technologies, munitions processing costs data are proprietary and will depend on numerous factors, including the number of munitions to be processed, whether or not they can be easily demilitarized or require pre- or post-processing, state-specific permit requirements for technology operation and treatment of process residues, and the need for replacing or repairing technology components over time—for example, periodic replacement of the inner vessel and other equipment will also affect costs. Also, all of the experience with DAVINCH is with chemical munitions, hence; any cost data would not be comparable to the demilitarization of conventional munitions.

CONTAINED BURN AND ROCKET AND MISSILE MOTOR FIRING CHAMBERS

CB and contained rocket and missile motor firing systems have been developed, tested, and implemented at several locations for different demilitarization operations as an alternative to open burning and static firing. The technological approach for CB typically involves a thermal treatment chamber (TTC) containment vessel or tank in which energetic materials are burned or into which rocket motors are fired. In some applications the materials are placed inside the vessel and ignited as a batch; in other applications wastes are fed semi-continuously into the vessel, where they are ignited. The vessel captures the combustion gases, which are then exhausted through a PAS. Gases are usually filtered through high-efficiency filters to remove particulates and then ducted through wet or dry scrubbers, before being vented through a conventional stack to the atmosphere. Because there is no "controlled flame device" in the thermal treatment chamber, most CB facilities are permitted as RCRA Subpart X miscellaneous treatment units rather than as incinerators. Most states also require an air permit.

CB and contained rocket and missile motor firing chambers can be scaled to meet workload requirements and are designed for automated feeding and discharge of materials for safety in materials handling. The technologies are suited for a majority of applications where OB and static firing are conducted.

In the text below, representative applications of CB technology are provided followed by an example of a larger application where 16 million lb of M6 propellant and Clean Burning Igniter (CBI) were destroyed. This is followed by

[24] "Updated Operation and Maintenance Activities of DAVINCH System," p. 23, presentation by O. Shimoda et al., Kobe Steel, at CWD2015 London, June 2015.

[25] Ibid., p. 24.

[26] Response A5-2 by Kobe Steel to committee question about size of donor charge: "Sometimes HE shells generate very large and heavy fragments with very high velocity, which may damage the inner chamber seriously. Therefore, to make the fragments smaller and slower, the donor charge may be increased."

examples of historic contained rocket and missile motor firing applications and a description of an existing large facility for destroying ammonium perchlorate rocket and missile motors. These facilities use both batch and semi-continuous feed approaches and address a wide range of demilitarization needs. Last, a CB technology that uses an external heat source rather than a burner (flame) to destroy energetics is described and its use in the demilitarization of several munitions is summarized.

Contained Burn Chambers

A variety of CB thermal treatment units that use a burner to demilitarize specific munitions in the stockpile have been developed by Army contractors. Three examples are:

1. A cluster munition grenade thermal treatment unit is used by General Dynamics to process M42 and M46 grenades. These are components of a 155 mm high-explosive, dual-purpose projectile (DODIC D563), that would otherwise be open detonated.
2. Semi-continuous feed CB chambers have been designed by El Dorado Engineering. These are scaled and designed to accommodate different waste types with feed and burn stations that are integrated within a single containment vessel combined with an advanced pollution control system. This design allows customized stations to handle small detonating/fragment producing items in one station, bulk materials in another station, and contaminated combustible wastes in another station. These systems are generally smaller in scale and are best suited for applications involving relatively small quantities of energetic material wastes. They have been fielded as a replacement to OB through modification of existing RCRA Subpart X units at several private commercial facilities.
3. El Dorado Engineering also designed a CB system capable of batch operations with 60 lb of waste propellant per batch.[27] The unit was tested to demonstrate the technology on a wide variety of propellant types prior to full-scale design. The test vessel was 4 ft. in diameter and 10 ft. long and was rated to a working pressure of 110 psi. All of the propellants burned acceptably; the pressure reached a peak of about 50 psi within about 50 seconds, and then fell to about 10 psi in another 50 seconds. Most of the particulates settled out in the tank, and the remaining gases were vented through pollution control equipment. More than 200 test burns were conducted. Residues were tested for reactivity using differential scanning calorimetry and found to be nonreactive. Based on these test results, a full-scale system was designed with 8 ft. diameter vessels, 30 ft. long. The multiple vessel system design was capable of disposing of approximately 500,000 lb per year.

Throughput Capacity

Throughput capacity for contained burn chambers will vary greatly and will depend on the munition being processed (e.g., rocket and missile motors, grenades, mines). They can be scaled to meet operational requirements. El Dorado Engineering has stated that these units are "highly scalable," with capacities ranging from 10 to as much as 50,000 lb per burn cycle.[28] Another technology provider stated that they have the capability to process 670 ammonium perchlorate rocket and missile motors per week on a 24 hour per day, 7 days per week basis and can process 72,000 M42 and M46 grenades per day.[29]

Environmental Impacts

For contained burn systems, gas streams are treated via PAS prior to release to the atmosphere. PAS includes cyclones or filters to remove particulates from exhaust gases, spray towers and demisters, and afterburners to ensure complete combustion of energetics. These components are used to ensure compliance with RCRA regulations and state air permits. Secondary wastes are treated and disposed in accordance with RCRA requirements.

Personnel Safety

If operated properly under engineering controls, CB systems are expected to be safe with minimal worker and public exposure to energetic materials or effluents. For example, in one automated industrial system, more than 160 million grenades were demilitarized with only 15 grenade detonations taking place, and these events occurred behind safety walls.[30]

Cost

The capital and operating costs of commercially available CB systems vary greatly and depend on capacity, complexity, the materials being demilitarized, expected maintenance requirements, the number of munitions processed, the ability to recover and reuse materials, and other factors. Because cost data are considered to be proprietary, they were not available to the committee for most applications.

[27] El Dorado Engineering, "Contained Burn Process Description and Applications," no date.

[28] Briefing to committee by El Dorado Engineering, December 2017.

[29] General Dynamics, response to committee questions, April 2018.

[30] Ibid.

A Large Contained Burn System Application: Camp Minden, Louisiana

As a result of an accidental detonation of propellant at Camp Minden, Louisiana, an investigation resulted in the discovery of millions of pounds of improperly stored propellants and igniters. The challenge was to identify the best method to safely destroy the 15.7 million lb of single base (nitrocellulose) M6 propellant and 300,000 lb of CBI material in storage at the site expeditiously and in a manner that protected public health and the environment. Following a comparison of alternatives,[31] a CB system was selected as the technology best suited to destroy these propellants and explosives (Figure 4.1). The design, construction, and installation of the CB facility took less than 9 months.

The description below provides an example of what a high-capacity CB technology consists of; this application was for a quantity of propellant that was much larger than exists at the stockpile sites (primarily bagged propellant charges), and a facility of this capacity is unlikely to be needed for the disposal of energetics managed by PD Demil. The Camp Minden facility is currently inactive.

The CB system at Camp Minden used a vertical cylindrical steel thermal treatment chamber. Propellant was placed on a cold burn pan in preparation for treatment and treated in a batch process. The pan was then placed by operators using a forklift on a loading shelf located outside the thermal treatment chamber. Loading of the pan into the chamber was accomplished remotely with no one in the area. A door similar to an autoclave sealed the chamber, satisfying the ignition system interlock.

After placement of the tray on the loading system, all operations were conducted remotely to enhance worker safety. The integrity of the ignition system (continuity and resistance) were remotely checked and monitored prior to ignition. The operator ignited the material using an electronic ignition system. Once ignited, the flame rose vertically, mixing with the air in the sealed chamber at high temperature with a residence time allowing for efficient combustion of the propellant. The exhaust was then metered using a motorized control valve to control flow into the PAS. The PAS achieved CAA Maximum Achievable Control Technology (MACT) standards. The major products of combustion of M6 and CBI were carbon dioxide (CO_2), water (H_2O), and nitrogen (N_2). Potential minor products of combustion included solid ash or particulate matter (PM) and gaseous species: carbon monoxide (CO), nitrogen oxides (NO_x), and volatile organic compounds (VOCs). Upon completion of the contained burn process cycle and once the chamber pressure was confirmed to be under vacuum, the autoclave door opened and the shelf with the empty tray was unloaded from the chamber remotely to the safe loading area. Personnel confirmed via camera that conditions were safe for opening the device. Personnel then removed the empty burn tray for additional cooling and placed a cold tray with M6/CBI material on the shelf to repeat the cycle.

Throughput Capacity

The CB system was designed for a maximum throughput rate of approximately 63,360 lb of propellant per day (880 lb of M6 per 20- to 25-minute cycle). The facility safely destroyed approximately 15.7 million lb of M6 propellant in less than 1 year after startup. Similar but smaller CB chambers, sized to meet site-specific needs and with appropriate pollution abatement systems, should be capable of incinerating other single-base propellants in the stockpile—for example, M1 (DODIC D675) and possibly double-base (nitrocellulose and nitroglycerin) M2 propellants (DODIC D676).

Environmental Impacts

The continuous emissions monitoring system ensured that emissions remained low. Stack testing confirmed emissions were well below permitted levels as indicated below:

- VOCs: Allowable 10 ppm; actual <0.01 ppm
- CO: Allowable 20 ppm; actual <0.01 ppm
- NO_x: Allowable 250 ppm; actual <0.01 ppm
- All principal organic hazardous constituents: Nondetect
- Destruction and removal efficiency: >> 99.999 percent
- PM: <<0.0016 gr/dscf

Personnel Safety

Numerous remote controls and loading equipment were integrated into the design to maximize worker safety. Once the pan was placed on the loading shelf, subsequent operations were accomplished remotely. The operator ignited the material remotely using an electric ignition system. Upon completion of the burn, the empty tray was remotely unloaded to a safe area. Confirmation for safely opening the device for the next cycle was confirmed by camera.

Cost

The proposed cost for the Camp Minden contained burn system, including the advanced PAS and a continuous monitoring system, was $28,062,384,[32] or about $3,500 per ton for the combined 16 million lb of M6 propellant and CBI destroyed. Costs were proposed for three phases: (1) mobilization and site preparation for permitting, licensing, design,

[31] U.S. EPA, "Preliminary List of Potential Technologies for the Destruction of M6 at Camp Minden, draft 2/22/15."

[32] Letter from Louisiana National Guard, Office of the Adjutant General, to EPA, Region 6, April 14, 2015.

FIGURE 4.1 Camp Minden contained burn system. SOURCE: R. Hayes, president, El Dorado Engineering, “El Dorado Engineering’s Technologies for the Demilitarization of Conventional Munitions,” presentation to the committee, October 24, 2017.

and construction ($8,670,104); (2) disposal operations to destroy the M6 propellant and CBI ($14,293,200); and (3) site restoration and project closeout ($475,643). These three phases cost $23,438,947. The remaining $4,623,437 was for a maximum removal efficiency PAS and the continuous emissions monitoring system. The final contract for the Camp Minden CB system approved a payment of $27,369,485.[33]

Contained Firing of Rocket and Missile Motors

Static firing of rocket and missile motors is a form of OB that is gradually being replaced by contained firing in enclosed facilities having pollution abatement equipment that reduces air emissions. Three examples of contained rocket and missile motor firing applications that are no longer in use are given below. This is followed by a description of an existing PD Demil facility for contained rocket and missile motor firing that, as of early 2018, was undergoing acceptance testing. The three historical contained rocket and missile motor firing applications are as follows:

1. Bechtel, Nevada, under the direction of United States Army Defense Ammunition Center & School, contracted with El Dorado Engineering to design and fabricate a system to dispose of Shillelagh[34] missile motors at production rate and scale. The motors consist of double-based propellant. The application used a pressure vessel approach, with each missile treated in a single batch. The missiles were placed in a holder and mated to the vessel under an offgas collection

[33] Camp Minden MG Destruction, Contract, June 17, 2015, and State of Louisiana Office of State Procurement letter Amendment #1 to Emergency Contract for the Camp Minden M6 Destruction, dated April 11, 2016.

[34] The Shillelagh missile was a high-explosive anti-tank (HEAT) missile containing a shaped charge warhead. It was intended to be fired from tanks.

hood. They were ignited using on-board ignition systems, and the primary grain and gas generator burn at the same time, exhausting into the 45 psig rated vessel. When the missile firing was complete, the gases were contained until they were cooled. The gases were metered through a baghouse and HEPA filter before discharge through a stack. The cycle was then repeated. The system was designed and permitted for a rate of eight missiles per hour.

2. Another system, installed at a General Dynamics Corporation commercial demilitarization facility in Missouri, utilized a semi-continuous feed of sawed Multiple Launch Rocket System (MLRS) rocket motor sections that were fed into the containment chamber and ignited with a pilot torch style ignition source. The exhaust gases were vented through a specially designed pollution abatement system to remove particulate and acid gases. The system was permitted under RCRA Subpart X. More than 1 million lb of propellant have been treated through this system.
3. A full-scale CB demonstration test of large rocket and missile motors was performed at Naval Air Weapons Station China Lake, California. The thermal treatment chamber was approximately 15 ft. in diameter and 80 ft. in length, equipped with a remotely actuated propellant loading system, an ignition system, and a pollution abatement system. The pollution abatement system was designed to scrub alumina particulate and hydrochloric acid from the exhaust gases, which are the primary products of combustion of the aluminized ammonium perchlorate (AP)-based propellants contained in these motors. Testing demonstrated that the peak pressures (about 70 psig) and temperatures reached in the chamber were consistent with the designed operating parameters. Complete combustion was achieved with very low CO levels. The pollution abatement system performed as designed with very efficient removal of particulates and hydrochloric acid.[35]

The applications described above, although no longer in operation, gave the Army and its contractors experience in the firing of rocket and missile motors in contained chambers. The China Lake facility was a predecessor to a larger ongoing rocket and missile motor CB facility being used by PD Demil, as described below.

[35] El Dorado Engineering: Contained Burn Process Description and Application, no date.

A Large Rocket Motor Contained Burn Application: Ammonium Perchlorate Rocket Motor Destruction (ARMD) Facility

In February 2014 the Letterkenny Munitions Center (LEMC) began the permitting and approval processes to establish a contained, thermal destruction capability for tactical solid rocket motors that contained Hazard Class 1.3 AP-based motors. Most motors consist of ammonium perchlorate (AP) as the oxidizer and an aluminum/rubber binder as fuel and comprise the largest portion of the missile demilitarization inventory. From 2014 to 2017 LEMC reported 4,613 AP rocket motors destroyed by OB static firing.

The ARMD facility consists of a preparation building; a segmentation building; a remote automated motor sealing, loading, and ignition completion (RAMSLIC) shelter, the 115 ft. long, 19 ft. diameter thermal treatment system chamber; a PAS; and an effluent waste handling system (Figure 4.2). Major components of the PAS include a spray tower, a venturi scrubber, a packed bed scrubber tower, and an induced draft fan. The facility has been approved by the DDESB and has received the necessary CAA permit and RCRA Subpart X approvals by the Pennsylvania Department of Environmental Protection.

The LEMC ARMD facility conducted the first MLRS demilitarization operation in January 2017. It is designed to conduct the demilitarization of a wide range of Army and other service rocket motors (~28 different rocket motors). Four rocket motor types will require segmenting to enable demilitarization in the ARMD facility. As of early 2018 small rocket motor family testing has been successfully completed.[36]

Throughput Capacity

Design throughput for the system is 10,000 cycles per year. The facility is designed to process both intact and segmented rocket motors, with a maximum propellant load of 805 pounds per batch cycle and a maximum throughput rate of three cycles per hour. Under the RCRA Subpart X permit, the maximum amount of propellant (NEW) treated is not to exceed 32,100 pounds per day and the maximum number of firings is not to exceed 60 per day. The actual propellant NEW treated per day will vary due to differences in rocket motor sizes being processed.

Environmental Impacts

The ARMD facility pollution abatement system achieved a greater than 95 percent reduction in HCl and greater than 98 percent reduction in particulates in stack testing. The process produces solids, primarily aluminum oxide, that have been tested and shown to be a nonhazardous waste, as well

[36] Committee visit to LEMC, October 26, 2017.

FIGURE 4.2 Ammonium Perchlorate Rocket Motor Destruction Facility thermal treatment chamber. SOURCE: R. Hayes, president, El Dorado Engineering, "El Dorado Engineering's Technologies for the Demilitarization of Conventional Munitions," presentation to the committee, October 24, 2017.

as a magnesium chloride brine solution that testing has also shown to be a nonhazardous waste.[37]

Personnel Safety

Operators are required to prepare the rocket motors for firing in the chamber. The motors are unpacked, and inert fins are removed. Following manual insertion of an igniter and transport to the motor loading area, the operators retreat to a control room, where the motor is remotely ignited. The motor is washed down (while still in the chamber) to cool it and remove residual HCl prior to the operators manually unloading the chamber with an overhead crane. For ease of operations and for operator safety, the neutralizing reagent used in the PAS is magnesium hydroxide. A full-system failure modes and effects analysis (FMEA) and hazards analysis have been performed on the system and an approved SOP is in place for operations.[38]

Cost

Design, construction, and installation costs were not provided to the committee. PD Demil states that operational costs have not been established since the process is still in acceptance testing.[39]

Static Detonation Chamber (SDC)

The SDC is a contained chamber in which munitions are destroyed as a result of their being externally heated in a closed vessel with either a detonation or, more usually, a slower deflagration of the energetics in the munition taking place. As such, it is considered to be primarily a CB chamber, although it does have CD capabilities. A representative SDC is shown in Figure 4.3, and a cutaway of the treatment chamber is shown in Figure 4.4.

The SDC is a near-spherical, electrically heated, armored dual-walled stainless steel chamber with an inner diameter of 1.2 meters for the SDC Model 1200 (different models can

[37] Information provided to committee by PD Demil, April 2018.
[38] Ibid.
[39] Ibid.

FIGURE 4.3 Static Detonation Chamber. SOURCE: H. Heaton, Dynasafe, "The Static Detonation Chamber and Conventional Demilitarization," presentation to the committee, October 23, 2017.

have different inner diameters). Munitions are fed into the chamber through two offset loading chambers, each having its own hydraulically operated door and inflatable seal. The upper loading chamber has airlock doors and the lower loading chamber has a blast door between it and the detonation chamber. The doors, loading chambers, and detonation chamber are all designed to resist and contain the overpressure from a detonation of up to 23 pounds for non-mass detonating materials. The SDC is permitted for detonations of up to 5.29 lb NEW for mass detonating materials (Hazard Class 1.1) and up to 18.4 lb for non-mass detonating materials (Hazard Class 1.2 and above).[40]

The interior of the detonation chamber is not open to the atmosphere. Munitions are dropped into the chamber from above and onto a scrap bed heated to 932°F-1,022°F (500°C-550°C) at the bottom of the chamber. The chamber is heated with electrical resistance elements to a temperature of 1,022°F-1,112°F (550°C-600°C), resulting in deflagration, detonation, or burning of the munition's explosive fill.

The detonation chamber is periodically emptied by disengaging from the lower loading chamber and being rotated nearly 180 degrees in order that most of the munition fragments can be dropped into a scrap bed in a bin. Some of the scrap is retained as a bed for the next series of munition feeds. Following scrap removal, the chamber rotates back to an upright position.

Offgases are transferred to a heated buffer tank/cyclone and thermal oxidizer operated at 2,012°F (1,100°C), followed by a quench, aqueous scrubbers, activated carbon filters, and other pollution abatement equipment that may be required by permits. Scrubber liquids are recycled back into the process, resulting in no liquid waste discharge.

Throughput Capacity

The SDC located at the Anniston Army Depot (ANAD) in Alabama operates under a RCRA Subpart X permit and has demilitarized a variety of munitions and energetics, including several that exist in the conventional munitions

[40] T. Garrett, site project manager, ANCDF, PEO ACWA, "Anniston Static Detonation Chamber Status," presentation to the committee, August 23, 2017.

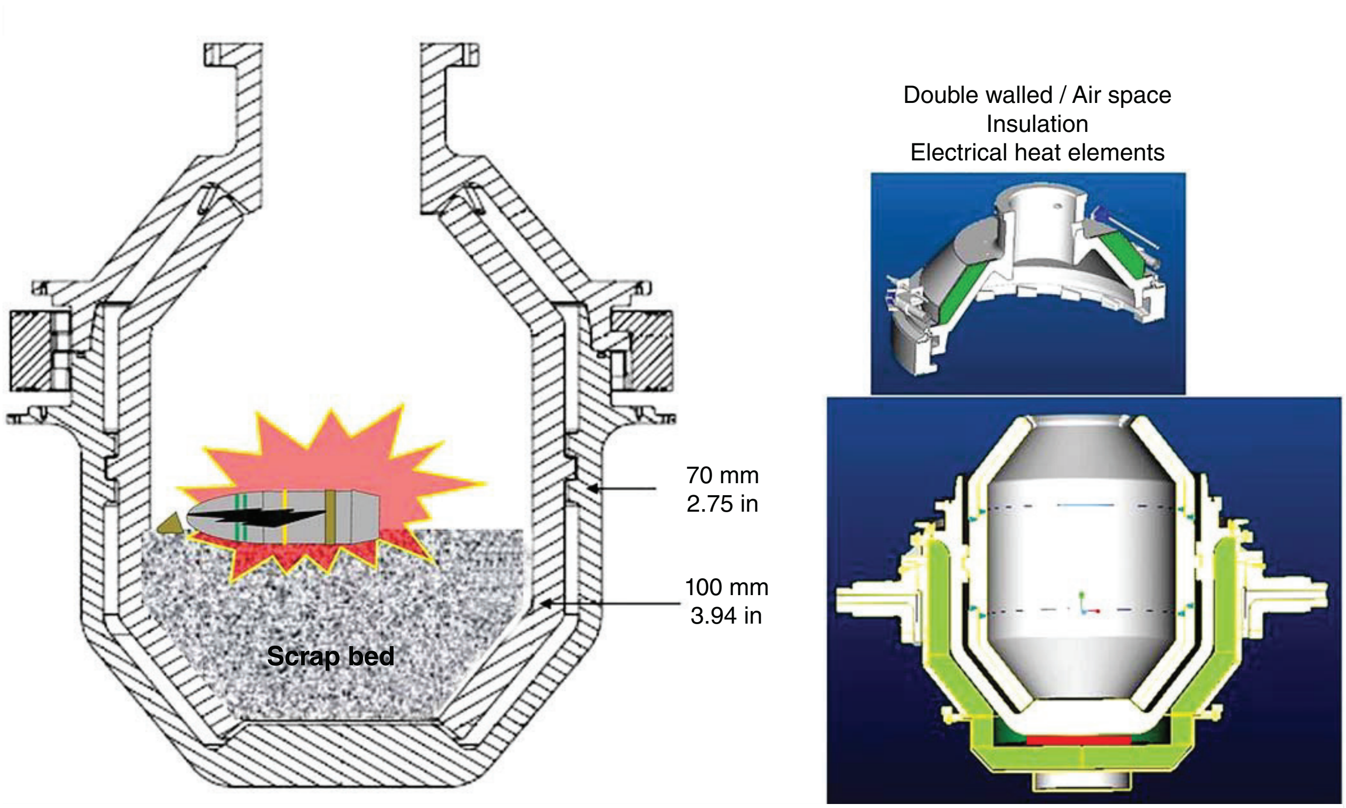

FIGURE 4.4 Static Detonation Chamber treatment chamber. SOURCE: T. Garrett, site project manager, ANCDF, PEO ACWA, "Anniston Static Detonation Chamber Status," presentation to the committee, August 23, 2017.

stockpile (B5A Account). These include more than 46,000 60 mm cartridges (DODIC B632); more than 9,600 90 mm cartridge canisters (DODIC C410); bagged propellant charges (DODIC D541); 265 2.75 in. warheads (DODIC H842); 20,000 mechanical time and superquick fuzes (DODIC N285); and almost 37,000 point-detonating fuzes (DODIC N335).[41]

Throughput rates depend on the size and complexity of the munition processed, the munitions' NEW, and the time required for them to heat up. Examples of estimated SDC throughput rates for processing munitions in the conventional munitions stockpile that are currently being demilitarized using OB or OD are given in Table 4.1.[42]

The SDC appears to have the capability of processing a large variety of munitions, some of which can be fed directly into the chamber and others that may require one or more preprocessing or downsizing steps as noted in Table 4.1. The SDC manufacturer notes that throughput rates are limited by "the ability of the SDC to absorb or reject heat from the feed materials."[43]

Environmental Impacts

All gaseous emissions from the SDC are held in a buffer tank prior to being treated in a pollution control system. Solid wastes, such as scrap metals, are held in the chamber at 1022°F (550°C) to render the scrap suitable for release for unrestricted use, allowing them to be recovered and reused. Dry salts from feed materials, spent filters, and collected dust are sent offsite for disposal. If the heavy metal content of the salts and collected dust render them hazardous materials, an RCRA-permitted treatment, storage, and disposal facility (TSDF) is used to dispose of them.

Personnel Safety

Risks to worker health and safety are considered to be low due to the use of an automated loading system and remote operation of the SDC. The largest risk to workers are possible burns from exposure to hot metals and dust inhalation from

[41] T. Garrett, site project manager, ANCDF, PEO ACWA, "Anniston Static Detonation Chamber Status," presentation to the committee, August 23, 2017.

[42] Dynasafe Responses to committee questions, January 28, 2018 (letter from Harley Heaton).

[43] H. Heaton, Dynasafe, "The Static Detonation Chamber and Conventional Demilitarization," presentation to the committee, October 23, 2017.

TABLE 4.1 Examples of Munitions That Can Be Processed in the SDC

Munitions Treated OB/OD (from 400 List)	DODIC #	Total Tons in B5A—as of September 30, 2017	Net Explosive Weight (NEW) per Munition	Processing Steps	Estimated Processing Rate (munitions/hour)	Processed in SDC
Cartridge, 60 mm HE M49A2/A4	B632	2,073.91	0.839	Direct feed.	50	Y
Cartridge, AF 30 mm high-explosive incendiary PGU-13/B A/B linked	B104	287.23	0.1019	Direct feed.	400	Y
Cartridge, 90 mm canister anti-personnel M590	C410	132.48	1.6	Direct feed.	50	Y
Cartridge, 81 mm HE M374/E1/A2/A3	C256	640.88	2.428	Direct feed.	50	Y
Cartridge, 105 mm TP-T M490 and E1/A1	C511	126.77	12.0881	Direct feed with propellant.	18	Y
Cartridge, 105 mm TPDS-T M724A1	C520	277.72	10.14	Direct feed.	18	
Cartridge, 90 mm canister anti-personnel M377	C601	421.28	9.057	Direct feed.	500	
Projectile, 155 mm HEAT M741 (Copperhead)	D510	1,389.47	14.759	Unmate, remove fuze, cut shaped charge, reduce NEW per feed.	13	
Charge, propelling 155 mm WB M119 Series without primer	D533	3,988.60	22.22	Remove lead foil, break up, and feed in two feeds.	10	Y
Charge, propelling 155 mm WB M4 Series	D541	2,041.39	14	Direct feed, may remove lead disc.	16	Y
M42/M46 submunitions only	D563		6.377	Remove copper cone/defeat shaped charge.	1,000	Y
Charge, propelling 8 in. GB M1	D675	93.71	14.313	Direct feed.	15	Y
Dispenser and bomb, ACFT CBU-87B/B (submunitions only)	E890	1,854.56	129	Remove submunitions, defeat shaped charge.	1	
Warhead, 2.75 in. HE XM/M151	H842	2,153.42	2.4	Unmate and cut rocket/warhead.	60	Y
Canister, mine HE F/XM/M87 Volcano	K045	215.56	7.598	Press internal components out of mine body.	81	Y
Fuze, M624F/mine anti-tank M15	K068	187.81	0.004	Direct feed.	11	Y
Mine, anti-personnel M18A1 with firing device	K143	168.57	1.57	Direct feed.	84	Y
Cartridge, engine starter MXU-4A/A	M158	1,201.69	8	Direct feed but spent case may contain hazardous materials. Process filters and salts may be contaminated.	28	Y
Dynamite, military M1 TNT (1375)	M591	420.79	0.39	Direct feed.	509	Y
Fuze, mechanical time and superquick M577/A1	N285	1,226.97	0.0016	Direct feed.	3,000	Y
Fuze, PD M557	N335	1,551.23	0.0536	Direct feed.	3,750	Y
Fuze, PD M739/A1	N340	1,558.74	0.0499	Direct feed.	4,091	Y

sorting scrap after removal from the SDC. However, these risks can be mitigated by requiring workers to wear appropriate industrial personal protective equipment (PPE) or by other engineering controls, such as using a ventilation hood.

Cost

The Dynasafe SDC 1200, located at ANAD in Alabama, is owned and operated by the Army. In addition to chemical munitions, this unit has processed tens of thousands of small conventional munition items, as listed in Table 4.1. Based on operating experience in the United States, the SDC appears to be cost competitive with other demilitarization technologies that process small to medium-size munitions—for example, rotary kiln incinerators. Labor costs appear to be moderate: several staff to operate the unit, two to four more staff in a control room, and additional staff to operate the SDC's pollution abatement system. As with other comparable technologies, the SDC will incur costs for setup, closure, operations and maintenance, regulatory compliance, monitoring, and disposal of treated residuals.

DEACTIVATION FURNACES/ROTARY KILN INCINERATORS

Deactivation furnaces and rotary kiln incinerators are systems that demilitarize small munitions, larger munitions that are suitably preprocessed, and munition components, within the size and NEW limitations of the system in question. They are CB chambers in that combustion takes place in a closed vessel with effluents being treated in pollution abatement systems containing afterburners, filters, scrubbers, and other equipment as needed. Some of them also have modest CD capabilities when processing small arms ammunition, fuzes, and other low NEW munitions. The technologies in this category that have been used by the Army and its contractors include, but are not limited to, the U.S. Army APE 1236, the El Dorado Engineering Explosive Waste Incinerator (EWI), the General Dynamics Rotary Kiln Incinerator (RKI), U.S. Demil's Decineration process using an electrically heated rotary furnace, and the U.S. Army's Bulk Energetics Disposal System (BEDS), where slurried energetics are fed to a rotary kiln incinerator. These are described below. Conventional rotary kiln incinerator technology has been adapted for small arms destruction and provides continuous processing. Centered on a hollow, tubular chamber, internal spiral rifling acts as a screw conveyor: the munitions are loaded at one end, transferred by the screw as the chamber rotates, and extracted at the other end. Munitions travel through the chamber in a heated environment, heat being supplied to the outside of the chamber (e.g., Decineration process) or to the inside of the chamber from a combustion flame (e.g., APE 1236). Overall treatment time for munitions is controlled by the rotation rate of the chamber. The tubular chamber may be segmented to match different temperature regimes or heating rates, or to allow some sections to be reinforced to withstand detonations when destroying explosive materials (e.g., APE 1236). Product gases are directed into a downstream pollution abatement system. Other thermal treatment technologies such as car bottom and flashing furnaces are described in the "Thermal Decontamination of Munitions Scrap" section of this chapter.

APE 1236M2

The APE 1236M2 is used to process small arms, primers, fuzes, and other small items. It can also be used as a flashing furnace for small projectiles after the energetics have been washed out. It is a fixed (nonmobile) 20-ft. long, 3-ft. diameter horizontal retort with a spiral internal element (baffle) that acts as a screw conveyor, moving materials through the unit from the feed end to the discharge end, where the oil- or gas-fired burner is located as the retort slowly rotates. The internal spiral flights are 10 in. high and are spaced about 30 in. apart. The side walls are 2.25 in. thick overall except in the center of the retort, where the side wall is 3.25 in. thick. It can process a single piece that is up to 5 in. in diameter and 18 in. long. The temperature at the discharge (burner) end of the APE 1236 is about 1,200°F and about 600°F-900°F in the middle sections.

The PAS for the APE 1236 includes a cyclone to remove dust, an APE 1405 afterburner to further heat combustion gases and destroy remaining organics, an APE 1404 high-temperature ceramic baghouse, an induced draft (ID) fan, and gas sampling equipment. A picture of the APE 1236 and its PAS is shown in Figure 4.5.

Throughput Capacity

The feed rate for the APE 1236 will vary; the range is usually 600-800 grains (0.086-0.114 lb NEW) per item at a typical rate of one item per second. For a processing rate of 800 grains/second, the throughput is 410 lb/hr NEW, although more generally, a processing rate of 240 lb/hr NEW is used (Sullivan, 2015).

Environmental Impacts

APE 1236M2 rotary kiln incinerators are permitted as Maximum Achievable Control Technology (MACT) units under the CAA and as incinerators under the RCRA. The PAS is not designed for dioxin or furan control. An upgrade to the PAS to replace the ceramic baghouse with a combination of an evaporative cooler and a fabric filter baghouse is under consideration to reduce dioxin and furan emissions that would be associated with some energetics, expanding its treatment capabilities.[44]

[44] Ibid.

FIGURE 4.5 APE 1236M2 and pollution abatement system. SOURCE: J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of the Product Director for Demilitarization, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee, August 22, 2017.

Personnel Safety

Safety information that pertains to technology-specific equipment and lower-level safety incidents was requested but not provided to the committee.

Cost

In a study of potential productivity improvements in the operation of the APE 1236M2 incinerator, it was noted that there are "limited tools for measuring actual demilitarization costs";[45] thus, cost information was not available to the committee.

Explosive Waste Incinerator (EWI)

The EWI, designed by El Dorado Engineering, is an updated version of the APE 1236. It processes SAA, fuzes, projectiles up to 30 mm, grenades, bulk explosives, and propellants. It can also be used as a flashing furnace to thermally decontaminate metal parts. Munitions and configured items are fed into the EWI on an 8-in. wide pan conveyor. Bulk materials are placed in a combustible container that can carry material containing up to 5 lb NEW per load. Larger munitions can be handled after a size reduction preprocessing step—for example, use of a band saw, shear, or water jet cutter.

Throughput Capacity

The EWI can process a wide variety of intact SAA at a rate of up to 25,000 rounds per hour (approximately 1,500 lb/hr). Fuzes can also be processed at rates ranging from 400 to 2,000 items per hour. The EWI can process bulk explosives at a rate of up to 330 NEW lb/hr (150kg/hr), including Comp B, Comp A3, TNT, M1, M6, and M9 propellants. It can also flash materials at a rate of approximately 2,000 lb/hr.

[45] Ibid.

Environmental Impacts

The EWI PAS is designed to meet regulatory requirements. It may include a cyclone to separate particulates, an afterburner, a fabric-filtration baghouse, a gas cooling system, an ID fan, and continuous gas emissions sampling equipment. Metals (typically including steel, brass, and lead) are discharged from the rotary kiln incinerator and are separated (with optional automated equipment) for recovery and recycling.

Personnel Safety

The EWI rotary kiln incinerator provides primary containment of blast and fragments. Internal flights also provide containment and charge separation so that detonations in one section cannot propagate to adjacent sections. The rotary kiln incinerator is situated in an enclosure designed and verified by testing to contain blast and protect operators in the feed room from negative consequences (including hearing loss) from the maximum credible event inside the rotary kiln incinerator. Control interlocks are also used to notify the operator and take corrective actions in the case of a failure of the system.

Cost

The EWI vendor states that the cost of an EWI system with advanced pollution controls ranges from $3 million to $6 million, depending on the site location and options selected.[46] Other cost information was not made available to the committee.

Rotary Kiln Incinerator (RKI)

The General Dynamics RKI is also physically similar to the APE 1236. The RKI is 46 ft. long versus the 20 ft. length of the APE 1236. It can process HE munitions up to 40 mm in size and some non-HE munitions up to 60 mm—for example, grenades, fuzes, cartridge- and propellant-activated devices, propellants, and bulk explosives. As with the APE 1236, the burner is at the discharge end of the RKI and uses natural gas. The PAS includes a secondary combustion unit (afterburner), a spray dryer, a baghouse, and filters.

Throughput Capacity

The RKI throughput varies with the munition processed and is up to 600 lb/hr (NEW) and up to 3,100 lb/hr (total weight)—somewhat greater than the APE 1236. As with the other RKIs, larger size or higher NEW munitions need to be disassembled or otherwise downsized (e.g., by a band saw or a waterjet) prior to feed.

[46] El Dorado Engineering, response to committee request, May 2018.

Environmental Impacts

The air pollution control system (APCS) for the RKI contains an afterburner, a spray dryer, and a baghouse. The system uses waste feed cutoffs to shut down the material feed system in the event that an emission limit is approached. This control system does not allow material to be fed into the RKI until emissions are below predetermined operating levels.

Personnel Safety

The RKI uses automated equipment to process munitions once they are in a state where they could be a hazard to operating personnel. The automated equipment includes size reducing munitions and submunitions into components that can be thermally treated in the RKI.

Cost

Cost information was not made available to the committee.

Decineration

The Decineration process, developed by U.S. Demil LLC, uses a horizontally mounted rotary kiln (Harper International rotary kiln) to demilitarize small arms ammunition and munitions such as mines, canisters, and fuzes. It differs from the APE 1236 and other kiln-based incineration technologies in that there is not a burner at the discharge end; instead, heat is applied externally to the kiln to decompose long molecular chain energetics such as nitrocellulose and nitramines into shorter chain light hydrocarbons by fracturing carbon-carbon, carbon-nitrogen, and other bonds. The decomposition takes place at temperatures of 450°-750°F without contact between the material being processed and the external heating source. Following treatment in the Harper kiln, particulates are removed in a PAS that includes a multistage wet scrubber, an induced draft fan, and an electrically initiated catalytic convertor (oxidizer). From a regulatory standpoint, Decineration is considered to be a nonincineration, thermal process in that it does not destroy the energetics in the rotary furnace but decomposes them to organic vapors, allowing separation of the energetics from the metal components of the munitions.

U.S. Demil states that an existing unit has a NEW of 7.03 lb TNT-equivalent and that a thicker wall unit can have an NEW of 45 lb TNT-equivalent.[47] This process has been used to demilitarize 22 DODICs, including one in the stockpile that has been open detonated: the N285 fuze.[48] The other 21 DODICs that have been processed include a variety of

[47] Letter from David Kautz, president, U.S. Demil, LLC, to James Myska, NAS program officer, no date.

[48] "Decineration™—A Comparative Economic Study: Report of Findings," prepared by U.S. Demil, LLC, July 3, 2014.

fuzes, 20 mm and 40 mm cartridges, primers, blasting caps, and other small munitions.

Throughput Capacity

As with other contained burn chambers, processing rates will vary with the munition being treated. U.S. Demil states that a pilot scale demonstration of the Decineration process at the Tooele Army Depot had a production rate of 500 lb/hr NEW but that this production rate was capped by the state of Utah's permitting conditions.[49] A total of 21.8 tons of material was processed.

Environmental Impacts

As noted above, Decineration is considered to be a non-incineration process. The state of Indiana considers it to be a materials-recovery process since metal components are separated from energetics, which are volatilized, and can be reclaimed as scrap metal.[50] The process operates pursuant to an Indiana Department of Environmental Management (IDEM) letter of determination that no RCRA TSDF permit is required because the process would be considered materials recovery under the Military Munitions Rule (MMR; 40 CFR 266.202(a)(2)).[51] It is permitted in the state of Utah, which is not an MMR signatory state (see Appendix C), as a Subpart X miscellaneous treatment unit. Although it does not produce solid or liquid wastes, the "emissions/APCE" (air pollution control equipment) was cited by EPA as an environmental concern in a preliminary compilation of possible alternative technologies for destroying M6 propellant at Camp Minden, Louisiana.[52]

Personnel Safety

U.S. Demil states that in the pilot scale demonstration of the Decineration process at the Tooele Army Depot there were no high-order or safety stand down events.[53] Other safety information is not available.

Cost

As an example of net operating costs, U.S. Demil states that for pilot scale testing at the Tooele Army Depot, where 21.8 tons of materials were processed by the Decineration process, operation costs were $1,083/ton, waste disposal costs were another $7/ton, and the value of recovered materials (scrap metal) were $1,027/ton. Thus, a net cost of $63/ton was reported for this application.[54] These figures may not be representative of operating costs for other applications.

Bulk Energetics Disposal System (BEDS)

BEDS is a CB technology developed to destroy bulk energetics such as propellant. It is described by the Army as a "process of disposing bulk propellants and explosives via water slurry feed into a refractory-lined rotary kiln incinerator with an afterburner. The slurry feed system reduces the size of propellant pieces and prepares a water-based slurry for feeding to the rotary kiln incinerator. The propellant is prepared using a wet grinder, a slurry mix tank, a spray-water tank, and a slurry feed tank. The rotary kiln incinerator is equipped with two burners to consume all combustibles. The system includes a PAS consisting of an evaporative cooler, a hydrated lime hopper/injector, a baghouse, an induced draft fan, a continuous emissions monitoring system, and an exhaust stack."[55]

The BEDS is intended to demilitarize single-, double-, and triple-based bulk propellants in the form of fine powders, grains, extrusions, sticks, rolls, and other shapes. Other propellants currently loaded in munitions may, in the future, be treated following removal of the propellants from the munitions. BEDS is omnivorous, with 43 energetics identified as potential feedstock.[56] Propellant is fed as a 25-percent-weight propellant and 75-percent-weight water at a slurry feed rate of 2,200 lb/hr or 550 lb (0.275 tons) of propellant per hour.

Throughput Capacity

The BEDS capacity is limited by permit conditions; in the state of Nevada, where a BEDS unit was installed and permitted, but is not currently in use, the total quantity of NEW in waste munitions to be treated in BEDS was limited to 858 tons per calendar year, although this was subject to change upon completion of a Cumulative Human Health and Ecological Risk Assessment (HHERA).[57] Processing 858 tons per year is equivalent to a processing rate of 550 lb (0.275 tons) of propellant per hour for 12 hours per day and for 260 days per year.

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[49] Communication from David Kautz, U.S. Demil, to the committee, March 29, 2018.

[50] Letter from Indiana Department of Environmental Management dated June 14, 2016.

[51] See Chapter 6, n. 49.

[52] See https://www.epa.gov/sites/production/files/2015-03/documents/9545941.pdf.

[53] Communication from David Kautz, U.S. Demil, to the committee, March 29, 2018.

[54] "Decineration™—A Comparative Economic Study: Report of Findings, Tooele Army Depot (TEAD) Test Location," U.S. Demil, LLC, July 3, 2014, p. 48.

[55] Hawthorne Army Depot Hazardous Waste Management RCRA Permit NEV HW0023, Section 7c: BEDS Incinerator Conditions, September 2013.

[56] Table W-1 in Waste Feed Characterization for BEDS (40CFR 270.14(b)(2)&(3) and 270.62(b)(2)(i)).

[57] Nevada Division of Environmental Protection, RCRA Permit NEVHW0023, September 2013, Section 7C, pp. 1-2.

Environmental Impacts

Wastes produced by BEDS include incinerator ash, calcium salts, and unreacted lime. The RCRA permit for BEDS states that the maximum particulate matter allowed is 180 mg per dry standard cubic meter and the maximum CO in the stack exhaust gas should not exceed 100 ppm over a 1 hour rolling average.

Personnel Safety

Information about personnel safety was not available due to insufficient operating experience with BEDS.

Cost

Information about the costs of installing and operating BEDS was not available due to insufficient operating experience.

NONINCINERATION ENERGETICS DESTRUCTION TECHNOLOGIES

Energetic materials can be destroyed using any of several nonincineration processes other than the CB and CD technologies described above. Those used include industrial supercritical water oxidation (iSCWO), for oxidizing and mineralizing munitions energetics and bulk explosives; stationary base hydrolysis oxidation, where energetics are mixed with a strong base and heated; and sulfur reduction chemistry to convert energetics to nonhazardous end products.

Other technologies exist but are not as well developed for munitions applications and were not reviewed by the committee. These include molten metal pyrolysis, alkaline hydrolysis oxidation, molten salt oxidation, wet air oxidation, biodegradation, and plasma arc incineration.

Industrial Supercritical Water Oxidation (iSCWO)

Supercritical water oxidation is a process that mineralizes organic materials such as propellants by reacting them with an oxidant such as atmospheric oxygen in water that is above its critical temperature of 705°F (374°C) and critical pressure (218 atmospheres or 3,206 psia). Above these values, water is in a supercritical state where it does not separate into gaseous and liquid phases. In a supercritical state, water becomes a solvent for organic energetics such as propellant. Dissolving energetic materials in supercritical water results in the rapid oxidation of the energetic material. The iSCWO technology operates at 1,202°F (650°C) and 3,400 psia.

iSCWO reactions to treat energetics would take place in a tubular, vertically oriented reactor pressure vessel constructed of appropriate materials, such as Hastelloy. A Hastelloy sleeve would be placed inside the pressure vessel and a sacrificial (replaceable) titanium liner would be placed inside the sleeve to prevent corrosion of the sleeve and the pressure vessel. Reactor liners for iSCWO units currently in use for other applications are 10 ft. high and have an inner diameter of 7.625 in. Feed material, such as slurried propellant, would be introduced at the top of the reactor vessel and move downward to exit at the bottom. The oxidation reactions are exothermic and the temperature of the reactor effluent is around 1,112°F (600°C). Quench water cools the effluent to below its critical temperature. Reaction products include water, CO_2, and salts.

The iSCWO technology can be used to treat any organic material that can be processed as a water slurry. Although the feed to an iSCWO reactor would be a mix of water and propellant or propellant wastes, there would be a need to reduce the propellant grain size beforehand to increase the surface area exposed for reactions. Thus, some preparation of the slurried propellant material—for example, grinding—would be needed prior to feeding it to the iSCWO reactor. The slurry mix would be 10 percent propellant and 90 percent water.

Throughput Capacity

The throughput capacity of an iSCWO reactor would vary with the reactor size and feed. iSCWO reactors developed for use at the Blue Grass Chemical Agent Destruction Pilot Plant (BGCAPP) in Kentucky will have a throughput of 3 gpm, and a larger capacity unit developed for processing propellant at the Blue Grass Army Depot had a capacity of 10 gpm. The destruction range for propellants varies from 130 to 240 lb/hr, depending on the propellant composition.

The footprint for an iSCWO unit as currently configured for other applications is roughly 25 ft. long, 8 ft. wide, and 15 ft. high, and a typical system includes pumps, the iSCWO reactor, a gas/liquid separator, gas and liquid effluent monitoring equipment, and process controls. The structure containing the three iSCWO units at the BGCAPP in Kentucky are much larger, however.

In its supercritical state, water is not a good medium for dissolving salts; thus, salts present in the feed stream or that form in the reactor may precipitate out of solution, resulting in accumulation on reactor walls and plugging at the reactor outlet. Salts can be managed by adding other materials to the reactor feed that allow salts to remain liquid and flow down the reactor walls to a quench zone at the bottom of the reactor. The extent to which propellant-based salts will accumulate in an iSCWO reactor and the need for using feed additives can be determined by running computer models followed by running tests. Depending on the waste feed, the titanium liner and the thermowells that contain thermocouples to monitor internal operating conditions may need to be periodically replaced, incurring downtime and costs; liner replacement is estimated to take about 4 hours and thermowell replacement about 3 hours.

For processing chemical agent hydrolysate, it was recommended that thermowells be replaced every 100 hours and the titanium liners replaced every 300-400 hours.[58] Replacement frequencies when processing slurried propellant, however, may be lower. When processing chemical agent hydrolysate, excess oxygen and a fuel (isopropyl alcohol) will be added. This should not be necessary when processing higher BTU content slurried organic wastes such as propellants.

Environmental Impacts

Emissions resulting from iSCWO processing will depend on the composition of the propellants and other organic energetics treated. Gases released to the environment are O_2, CO_2, N_2, and water vapor. Liquid and solid effluents include salts, water, and possible metallic oxides, depending on the feed. Any metals in the waste feed will be oxidized and can either be discharged or filtered as necessary. Halogens in the waste feed will be converted to salt and discharged as a liquid effluent. A 10 gpm unit processing a slurry consisting of 10 percent propellant and 90 percent water will consume 9 gallons of water per minute; a consideration if considered for use in an area with limited water resources. A SCWO system has been designed that will use reverse osmosis to remove salts from the water and recycle the water for use in the SCWO system. This system is undergoing systemization at the BGCAPP in Kentucky.

Personnel Safety

Although operating personnel are not exposed to the supercritical fluids in the iSCWO reactors, safety concerns have been identified in a previous study of iSCWO operations.[59] For example, personnel may be performing maintenance activities on an iSCWO unit while an adjacent unit is operating, potentially exposing them to "the unexpected release of steam due to failure of an operating unit."[60] Overall, iSCWO is expected to have the same potential industrial hazards to workers that are present with operating other high temperature and pressure systems, for example, a boiler. This issue is usually dealt with by enclosing the system in a metallic shield and separating the multiple units.

Cost

Costs per unit of material treated will depend on numerous site-specific factors including the quantity of material to be processed, the chemical and physical composition of the materials (affecting treatment requirements), RCRA and other regulatory treatment requirements, fixed costs in setting up and then removing the treatment units, operating costs, closure, and, if owned by the Army, acquisition costs. However, the cost of the unit and maintenance, especially considering the need for periodic replacement of titanium liners, is expected to be high.

Stationary Base Hydrolysis Oxidation

In this process, energetic wastes such as explosives (e.g., TNT, RDX, HMX) are mixed with a strong aqueous basic solution (e.g., NaOH) and heated to 90°C-150°C, resulting in alkaline hydrolysis of the explosives and decomposition of the wastes. The process has been demonstrated with batch feed of up to 122 lb of material every 30 minutes. There are some safety concerns. Hydrolysis of TNT, for example, would probably produce phenolics, the simplest of which, phenol, is corrosive to the skin and is a systemic toxin. The reaction is highly exothermic with foaming and rapid reactions taking place.

In a variant of this process, energetics are first dissolved in dimethylsulfoxide (DMSO). The dissolved explosives are then added to the basic aqueous solution (NaOH) at 60°C-90°C to form a reaction mixture where the reaction is between the dissolved explosive and the base and where the explosive is hydrolyzed. An aqueous acid solution is then added to the basic explosive-containing solution to neutralize it. Because the explosives are fully dissolved in DMSO prior to hydrolysis, there is greater control over the reaction rate, resulting in a more efficient reaction and less foaming. Reaction products are filtered to remove solids, liquids are evaporated to isolate salts that remain after the liquids evaporate, and gases are scrubbed and released to the atmosphere. While the process has been patented, it has not been demonstrated under operational conditions.

Stationary base hydrolysis oxidation equipment has been used at the Tooele Army Depot in Utah, where, between FY2005 and FY2011, it demilitarized 1,715 tons of small aluminum body cartridge actuated devices (CADs) and propellant actuated devices (PADs) by dissolving the aluminum bodies and energetic materials in a NaOH bath. The NaOH solution containing aluminum and energetic material was shipped to a hazardous waste contractor for treatment and disposal. The system is currently inactive because the inventory of CADs and PADs has been depleted, but it is available for future use if needed. The operating costs were $5,849,239, and the average cost was $3,411 per ton.[61] Information about environmental impacts and personnel safety aspects of this technology was not available.

MuniRem

The MuniRem technology utilizes sulfur reduction chemistry to reduce and degrade energetics to nonhazardous end products. MuniRem formulations are tailored to each application to ensure desired results. The MuniRem technology

[58] NRC, 2015, p. 19.
[59] NRC, 2013, pp. 26-27.
[60] Ibid.

[61] "Stationary Base Hydrolysis Oxidation Costs." Spreadsheet provided by PD Demil to the committee, April 2018.

has been demonstrated to decontaminate energetics-contaminated equipment, pipes, soils, and metal surfaces, and to dissolve and neutralize explosive residues and propellants.

Decontamination applications involve spraying the MuniRem solution on building walls, large equipment, and scrap metals (including bomb casings, bomb fragments, and breached projectiles), or soaking small-size equipment and scrap metals in MuniRem baths. The decontamination occurs when the contaminated surface is soaked in high-strength MuniRem solution (>15 percent) and allowed to react for 2-4 hours.

The MuniRem technology has been demonstrated and validated on several field scale projects. To date, it has been implemented as a component of several demilitarization efforts, including the on-site breaching and neutralization of recovered underwater munitions.[62]

Throughput Capacity

The MuniRem reduction chemistry process is slow. The vendor indicates that results are generally achieved in "hours to days" after application. The Army reports that throughput was 10 lb/hr for neutralizing ammonium picrate in a 100-gallon neutralization tank. A larger neutralization tank with a heat exchanger should be able to increase throughput rate, but this has not been demonstrated.

Environmental Impacts

The MuniRem process can be conducted indoors with little danger to the user or community.

Personnel Safety

Personnel require PPE to ensure no contact with the reactive chemicals when spraying the MuniRem solution or treating scrap metals in the MuniRem baths.

Cost

Although the MuniRem technology vendor states that MuniRem costs are "typically 30-50 percent less than traditional methods,"[63] cost data for specific applications of the MuniRem technology were not provided to the committee.

THERMAL DECONTAMINATION OF MUNITIONS SCRAP

During normal operations of Army ammunition plants and depots, considerable waste is generated that is contaminated, or is suspected of being contaminated, with propellants or explosives. According to DoD Instruction 4140.62, "Material Potentially Presenting an Explosive Hazard (MPPEH)," ordnance components that have been in contact with high explosives must be certified to be free from all explosive hazards. The certification process requires either two 100 percent visual inspections of every piece of scrap or appropriate treatment of the scrap. Appropriate treatments include chemical neutralization and thermal treatment. Following energetics destruction, various methods are available to clean contaminated metal and other surfaces to allow previously contaminated materials to be available for recovery, reuse, or release.

Flashing Furnace/Contaminated Waste Processor

Flashing furnaces (Figure 4.6) were originally designed to treat munition bodies contaminated with trace levels of energetics and were subsequently modified to thermally treat other materials (wood, clothing) contaminated with energetics.

In response to the Army's search for an environmentally acceptable method of disposal of these materials, the Ammunition Engineering Directorate (AED), Tooele Army Depot (TEAD), Tooele, Utah, proposed that a modification to the Army's standard APE 2048 flashing furnace would provide a system that could meet air quality requirements. The system concept was developed and named the Contaminated Waste Processor (CWP) and installed at TEAD in the early 1980s. Although the CWPs are no longer in service due to high operating costs, the APE 2048 flashing furnaces remain in service.

An APE 2048 Metal Parts Flashing Furnace was put into production in February 2007 at the Blue Grass Army Depot (BGAD), Kentucky. The system consisted of a 2-million BTU APE 2048 primary flashing furnace and a car-bottom secondary flashing furnace, both fueled with natural gas, and fitted with an enhanced PAS consisting of a baghouse, cyclone, gas coolers, and an 8 MMBTU natural gas fired afterburner. The car bottom furnace is currently idle, having been disconnected from the main unit by a blind flange.

El Dorado Engineering (EDE), West Jordan, Utah, has also developed flashing furnace technology to decontaminate explosive contaminated materials so that they can be sent for recycling. The EDE furnace is fully transportable but can also be installed in a fixed location. The trailer-mounted Transportable Flashing Furnace (TFF) is 5 ft. high, 7 ft. wide, and 17 ft. long. It can process loads of up to 10,000 lb with typical throughput rates of 5,000 lb of material in a single batch. Cycle times are 45-90 minutes, depending on the load size. A strongbox is used to thermally treat live items such as small arms ammunition and fuze components.

EDE has demonstrated the performance of the EDE TFF at several Army depots and Air Force bases (treating small munitions and rocket and missile bodies for recycling), range cleanups (live fuze components and range scrap), and

[62] Nzengung and Redmond, 2016.

[63] MuniRem Environmental: MuniRem® Technology Case Studies," p. 19, no date.

FIGURE 4.6 APE 2048 flashing furnace. SOURCE: J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of the Product Director for Demilitarization, PEO AMMO, “Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation,” presentation to the committee, August 22, 2017.

remediation operations at an ammunition plant (energetics contaminated equipment). At the Hill Air Force Base application, EDE established a batch limit of 25 lb NEW per load (no mass detonating materials) and loading rates and configurations for energetics and metals.

Throughput Capacity

Flashing furnaces are a proven technology to treat small amounts of energetic residue on metal munitions casings. The APE 2048 is designed to treat 8,000 lb metal per hour with a 2-million BTU/hr heat input. The BGAD Title V permit limit is 12,300 tons per year and 11,800 lb/hr maximum or 2,085 hours per year. The EDE TFF can process loads of up to 10,000 lb with typical throughput rates of 5,000 lb/hr.

Environmental Impacts

The environmental impacts from flashing furnaces, especially when equipped with air pollution abatement equipment, are low. For example, the APE 2048 at BGAD, which uses natural gas and has a PAS that uses a cyclone and a baghouse, reported particulate matter (PM) test results of 0.006 lb/hr, well below the allowable PM emission limit of 2.34 lb/hr.

Personnel Safety

Materials are typically loaded via a forklift. Operators then leave the area, and all other operations are performed remotely from a control room. The major personnel safety concern appears to be the risk of contact with hot treated metal during the removal and cool down processes. Flashing furnaces are a well-controlled and monitored process, with these systems designed to maintain a prescribed set point temperature for a prescribed time period to ensure that no energetic materials or residuals can remain. Upon completion of processing, materials are safe for general release and recycling with no reactive hazards present.

Cost

Cost information was not made available to the committee.

EMERGING TECHNOLOGIES

The technologies described up to now have all been demonstrated to completely or partially demilitarize conventional munitions. In this section, the status of several other technologies are summarized with respect to recent advances in their research and development. Several of these, described below, may have applicability to conventional munitions demilitarization in the future but are still in an earlier stage of development than the technologies described above.

Size Reduction

Liquid Jet Cutting (with or without abrasives)

Liquid jet cutting is a technology that has been reviewed previously and demonstrated at production scales (Poulin, 2010; Wilkerson, 2006). A number of technology development efforts are under way. Aside from water as a working fluid, ammonia and CO_2 have also been reported. Engelmeier et al. (2018) demonstrated improved jet cutting with CO_2 when the work piece and jet were maintained above atmospheric pressure, producing a liquid- or mixed liquid/vapor-CO_2 jet. Another benefit cited is that both work piece and cuttings are left dry at the end of processing. CO_2 has already been established (e.g., supercritical dissolution, discussed below, and dry ice abrasion) as compatible with the processing of munitions and as a strategy for minimizing or eliminating aqueous waste streams. Atmospheric release of the spent CO_2 gas would likely face scrutiny and require use of offsetting or recovered sources of CO_2. Other advances in jet cutting include the development of models to optimize work piece surface quality relative to the cutting rate and jet nozzle erosion rate. Implementation of such models could be used to accelerate or otherwise continuously and safely improve the munition processing rate, particularly after incorporating munition-specific processing history. To date, none of these advances has been demonstrated in a demilitarization context.

Jet cutting uses high-pressure, high-velocity liquid jets to separate whole munitions either by size or by component parts for further processing. In the jet cutting process, a focused liquid jet abrades the munition surface, with the depth and quality of the abrasion and other process qualities determined by the jet traverse speed. The working fluid may or may not contain suspended solid abrasive particles for added effect. Both the munition and the liquid jet working upon it may be submerged in liquid to reduce aerosolization and loss of the working fluid and to provide additional capacity for maintaining the temperature of the munition during the process.

Supercritical Fluid

Supercritical fluid extraction has been reviewed previously in the context of demilitarization (Poulin, 2010, p. 39). Supercritical fluids possess chemical and physical properties that are often advantageous for industrial and chemical processes. Explosive extraction from munitions using supercritical CO_2 (exceeding 31°C and 7.3 MPa) has been tested for reasons previously established (it is nontoxic, nonflammable, and less of a concern from an environmental perspective); however, results have shown low solubility of explosives in supercritical CO_2, diminishing the effectiveness of the approach. A recent advance has been to pair sonication (acoustic energy propagation at ultrasonic frequencies) with supercritical CO_2 explosive extraction, resulting in more rapid extraction of explosives from munitions than has previously been demonstrated.

Other Destruction Technologies

Photocatalytic

Liu et al. (2006) reported the accelerated degradation of RDX in wastewater by simulated solar spectrum radiation in the presence of catalyzed by TiO_2-impregnated activated carbon fibers. The measured degradation rates followed first-order kinetic behavior equaling or exceeding rates associated with the Fenton reaction.[64] Although repeated use of the catalyst suggested its gradual inactivation, tests showed it could be regenerated in a dilute hydrochloric acid solution. If reaction rates and throughput are both sufficiently high, photocatalytic treatment could be considered a more environmentally friendly treatment strategy than chemical or thermal treatments.

Ultrasonic

Sonication and sonochemistry use acoustic energy propagation through typically liquids and solids at ultrasonic frequencies for material and chemical processing. Studies of RDX degradation have shown that RDX in aqueous solution with sodium hydroxide or with suspended aluminum powders shows more rapid degradation as a result of sonication (Qadir et al., 2003). Sonication was also found to enhance the anaerobic biodegradation of RDX in aqueous solution at frequencies and intensities not resulting in loss of the microorganisms in the solution (Ince et al, 2018). If throughput were sufficiently high, such approaches could be viewed as more environmentally friendly than open burning of RDX.

[64] The Fenton reaction uses iron and hydrogen peroxide, combined in a Fenton's reagent, to oxidize organic materials (Barbusinski, 2009).

Bio-degradation

Aerobic and anaerobic degradation of explosives is a topic of current interest and research, with several groups reporting degradation efficiencies of explosive materials in aqueous solution using bioreactors.

Other Emerging Technologies

In addition to the technologies summarized above, the committee investigated several others with respect to their current research and development status. The committee was unable to find recent significant advances that could contribute significantly in the near future to the Army's conventional munitions demilitarization efforts. These technologies are:

- Size reduction
  - Pulsed or cavitating jets
  - Ultrasonic
- Washout, meltout, or ablation of explosives
  - Cryogenic
- Liquid nitrogen
- Liquid CO_2
  - Ammonia solvation
  - Solvent and acid extraction
  - Ultrasonic
  - Solid CO_2 particles
  - Microwave heating
  - Electrical induction heating
- Destruction
  - Molten metal pyrolysis
  - Oxidation
  - Alkaline hydrolysis
  - Molten salt
  - Mediated electrochemical
  - Wet air oxidation
  - Direct chemical
  - Adams sulfur

Finding 4-1. Contained burn chambers with associated pollution abatement systems designed to treat propellants and other energetics are available commercially and can be designed to meet the needs of PD Demil stockpile demilitarization as a substitute for open burning.

Finding 4-2. Contained detonation chambers that can demilitarize some conventional munitions and munition components exist; however, limited explosion containment capabilities and the need to prepare or preprocess munitions can limit the applicability of these chambers.

Finding 4-3. For some munitions, combinations of processing steps will be required to prepare munitions for treatment in a CB or CD chamber. Although this increases complexity and handling risks, if not conducted remotely using automated equipment, these steps enable the munitions to be demilitarized without using OB or OD.

Finding 4-4. Several of the emerging technologies are in early stages of research and development and have not been demonstrated under full-scale operating conditions. None of those examined by the committee are expected to make a significant contribution to demilitarizing munitions in the near future.

REFERENCES

Barbusinski, K. 2009. Fenton reaction – Controversy concerning the chemistry. *Ecological Chemistry and Engineering*. S 16(3): 347-358. http://tchie.uni.opole.pl/freeECE/S_16_3/Barbusinski_16(3).pdf.

DDESB (Department of Defense Explosives Safety Board). 2008. *Explosives Safety/Protective Design Review of Transportable Controlled Detonation Chamber- Models T-25, T-30, and T-60*. Alexandria, VA.

Englemeier, L., S. Pollak, and E.Weidner. 2018. Investigation of superheated liquid carbon dioxide jets for cutting applications. *The Journal of Supercritical Fluids* 132: 33-41.

Ince, E., G.O. Engin, M. Ince, and M. Bayramoğlu. 2018. Preliminary investigation on the optimum ultrasound frequency for the degradation of TNT, RDX, and HMX. *Global Nest Journal* 19(4): 733-738.

Liu, Z., Y. He, F. Li, and Y. Liu. 2006. Photocatalytic Treatment of RDX wastewater with Nano-Sized Titanium Dioxide. *Environmental Science and Pollution Research* 13(5): 328-332.

NRC (National Research Council). 2006. *Review of International Technologies for Destruction of Recovered Chemical Warfare Materiel*. Washington, D.C.: The National Academies Press.

NRC. 2009. *Assessment of Explosive Destruction Technologies for Specific Munitions at the Blue Grass and Pueblo Chemical Agent Destruction Pilot Plants*. Washington, D.C.: The National Academies Press.

NRC. 2013. *Assessment of Supercritical Water Oxidation System Testing for the Blue Grass Chemical Agent Destruction Pilot Plant*. Washington, D.C.: The National Academies Press.

NRC. 2015. *Review Criteria for Successful Treatment of Hydrolysate at the Blue Grass Chemical Agent Destruction Pilot Plant*. Washington, D.C.: The National Academies Press.

Nzengung, V.A. and B. Redmond. 2016. On-site neutralization of civil war munitions recovered from an underwater environment. *Marine Technology Society Journal* 50(16): 15-21.

Poulin, I., 2010. *Literature review on demilitarization of munitions*. Defence R&D Canada Technical Memorandum TM 2010-213. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA587546.

Qadir, L.R., E.J. Osburn-Atkinson, K.E. Swider-Lyons, V.M. Cepak, and D.R. Rolison. 2003. Sonochemical induced decomposition of energetic materials in aqueous media. *Chemosphere* 50(8): 1107-1114.

Sullivan, F. 2015. A Productivity Improvement Study of the APE-1236M2 Rotary Kiln Incinerator. Parsippany, N.J.: 2015 Global Demilitarization Symposium. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2015/demil/Sullivan.pdf.

Wilkerson, J. 2006. *Review of Demilitarisation and Disposal Techniques for Munitions and Related Materials*. NATO Munitions Safety Information Analysis Center, Brussels, Belgium.

Worsey, P.N., and D.A. Summers. 1984. *High Impact Velocity Testing of PBX Explosive*. A Progress Report on Contract N00164-83-C-0110. Crane, Ind.: Naval Weapons Support Center.

5

Evaluation Criteria

This chapter describes the criteria that the committee uses in evaluating alternative technologies that may be used in place of open burning (OB) and open detonation (OD). These criteria establish a means for comparing OB/OD to alternative technologies and allow for a systematic evaluation (see Chapter 8). The ordering of the presentation of the criteria in this chapter does not reflect any prioritization. The committee made no judgment on which are more or less important. The four criteria mentioned in the statement of task—throughput, personnel safety, environmental impacts, and cost—are discussed before additional criteria that the committee adopted.

Four evaluation criteria (throughput capacity, personnel safety, environmental impacts, and cost) were explicitly specified in the legislative language that became the committee's statement of task (National Defense Authorization Act for Fiscal Year 2017; SEC 1421, 2016). The committee applied five additional criteria: public health impacts, technology maturity, permitability or other approvals, monitorability, and public confidence. The committee has identified these as important criteria that also need to be considered when selecting alternative approaches to OB/OD. In selecting the additional five criteria, the committee considered criteria used in prior reviews of alternatives to OB/OD performed by the Army, the National Research Council (NRC), the Cease Fire! Campaign (see Appendix B), as well as the experience and judgment of the members of this committee.

The actual selection of alternative technologies for deployment would require a detailed engineering analysis based on the design and construction of each munition, which is outside the committee's scope and ability to conduct within the limits of this study. Further, the committee has chosen not to weight these criteria in terms of importance, because the committee firmly believes that the application of the criteria is munition, technology, site, and community specific. Clearly some criteria, such as personnel safety, need to be addressed rigorously, while others, such as maturity, might be desirable but would probably carry less weight than safety in selecting a specific technology. However, in all cases there needs to be a high level of confidence that the technology employed will demilitarize the munitions, that it can be implemented, and that it will be protective of workers, the nearby community, and the environment.

Munition demilitarization can be achieved via a combination of different technologies for each demilitarization process. Criteria used in selecting a treatment train not only need to focus on how effective a process is for a given munition but also need to take into account the ease with which a single process in such a treatment train can be upgraded or substituted so that the full treatment process can be easily adapted to a different type of munition. Consideration also needs to be given to the inclusion of a new promising technology, either as an integrated whole-munition process or as a process or component within an existing treatment train that might not have matured enough for immediate implementation when the treatment train was originally selected.

The committee's nine evaluation criteria are discussed in detail below. The committee provides a general narrative on how these criteria are applied to the alternative technologies in Chapter 8.

THROUGHPUT CAPACITY

Throughput is the rate of material that can be processed in a given time and can affect treatment costs. When a technology in and of itself provides treatment for the whole munition, determining throughput may be straightforward. Where treatment of the whole munition is based on a treatment train, including pretreatment, treatment, and post-treatment activities, determining throughput is less precise. It is important to identify any potential impacts on throughput that arise in a specific treatment configuration. Some factors that affect throughput can be mitigated relatively easily by adding more low-cost units or components (e.g., band saws for increased size reduction capability), but in other cases the cost of additional treatment capability (e.g., more or larger detonation chambers) may significantly increase costs. Ideally, the design of an overall treatment system would allow for the flexibility to process different munitions or to be reconfigured relatively easily for that purpose. Finally, it is important to recognize that whole-munition treatment systems may also have rate-limiting steps (i.e., loading, cooling, etc.) that affect their throughput.

PERSONNEL SAFETY

The avoidance and prevention of possible injury or death to workers conducting demilitarization operations is paramount. There are risks to personnel when transporting or otherwise moving an item to the facility or location where it will be processed, and there are risks in any preprocessing step (i.e., size reduction for alternative technologies or positioning munitions for OB/OD), in the treatment processing step, and during post-processing operations. The risks in all of these steps need to be identified, evaluated, and compared when selecting technologies. The safety risks inherent to alternative technologies and many individual steps within a treatment train can be mitigated with fully automated systems that minimize potential injury to workers.

In addition to injuries from catastrophic events, personnel health and safety risks from cumulative and aggregate direct and indirect exposures to potential toxicants associated with munitions and their destruction, including noise, also need to be considered.

ENVIRONMENTAL IMPACTS

A technology's ability to monitor, prevent, minimize, and control emissions of contaminants to all environmental media (water, air, soil), both during the demilitarization process and during process upsets, will determine its environmental impact. Furthermore, because various treatment technologies and pollution abatement systems result in the accumulation of secondary waste streams, it is important to consider the ability to meet the management and disposal requirements of these streams. Ideally, the treatment method is a complete solution with no long-term storage or disposal requirements for hazardous process waste streams.

Given the nature of the source material being treated, damage to equipment during treatment is possible. Hence, technologies for the demilitarization of conventional munitions need to have safety controls to prevent accidental releases of emissions, due to equipment damage, that have environmental or health concerns.

Other environmental impacts that need to be considered include those on ecosystems, including wildlife, marine, and aquatic receptors, as well as cultural, recreational, and commercial activities depending on such ecosystems.

Finally, the effects of vibration, noise and shock, visual plumes, and odor need to be considered, as they affect nearby communities.

COST

The costs of demilitarization technologies include capital costs, startup costs, operational and maintenance costs, and closure costs. Alternative technologies will have higher capital costs, which include development, design, construction, site preparation, and installation costs. Site preparation may also include the installation of required utilities. In addition to the capital costs, the implementation of any technology needs to account for permitting and regulatory compliance costs, including state, federal, and internal approvals, including those required by the Department of Defense Explosives Safety Board (DDESB).

Operation and maintenance costs comprise the costs of staff and operators including their procedural and safety training, scheduled and emergency maintenance, environmental and health monitoring, and the ultimate disposal of secondary wastes generated during the demilitarization process. Given that some munitions may have to be transported to sites where the appropriate demilitarization technology is available, transportation costs might need to be accounted for. Recycling may generate income streams that can reduce the overall operational cost of a demilitarization activity.

The cost evaluation of any demilitarization technology also needs to include closure costs. Equipment and sites will have to be decontaminated after closure. Given the much larger land area affected by OB/OD operations, and lack of containment, their closure costs are expected to be highest. Closure costs are usually not considered in the cost of demilitarization activities but need to be considered in an overall cost evaluation A life cycle cost (LCC) analysis is required if a true cost comparison of alternative technologies to OB/OD is to be made. According to Department of Defense (DoD) guidance, LCC is defined "as the cost to the government of a program over its full life, including costs for research and development; testing; production; facilities; operations; maintenance; personnel; environmental compliance; and disposal."[1] However, due to the lack of complete information on costs, the committee was not able to conduct an LCC.

PUBLIC HEALTH IMPACTS

The potential impacts of different technologies on public health is an important consideration. Permitted OB/OD and alternative technologies are required by the Resource Conservation and Recovery Act (RCRA) to be protective of human health and the environment.

The potential risks from exposure to all of the substances likely to be emitted during demilitarization of particular munitions (cumulative exposure) need to be considered, as do all significant potential sources of direct exposure and indirect exposure (aggregate exposure). Sources of direct exposure include air, water, and soil that a person might come

[1] For LCC definition, see https://www.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=e8a6d81f-3798-4cd3-ae18-d1abafaacf9f.

into direct contact with, while sources of indirect exposure include, for example, consumption of contaminated species such as fish or hunted game. Because susceptibility to the potential effects of exposure can vary with age and other factors, differences in susceptibility need to be evaluated during any risk assessment of alternative technologies.

Potential impacts on public health arising from all activities of a demilitarization process other than emissions would also need to be considered, such as the shifting of risk burdens among communities caused by transportation of munitions or munition components from one depot to another or to commercial facilities for treatment.

TECHNOLOGY MATURITY

When selecting technologies for conventional munition demilitarization, it is important to assess how far the technology has progressed toward being able to be used in industrial operation and hence the level of confidence that the technology will operate successfully once implemented. The closer a technology or system is to being ready for industrial use, the more mature it is. There are alternative technologies at several stages of maturity, ranging from novel ideas that have not yet been tested at the bench scale to treatment systems that have a proven track record and for which data are available for the effectiveness, throughput, cost, safety, maintenance requirements and downtime, environmental impacts, and reliability of the full-scale process.

A good measure of technology maturity is the number of munitions that have been treated successfully so far with a specific technology. The Army method when estimating technology maturity during the acquisition process is to assign a Technology Readiness Level (TRL) to the technology. TRLs range from 1 to 9, with 9 being the most mature technology. A TRL of 6 indicates a "system/subsystem model or prototype demonstration in a relevant environment," the lowest TRL considered by the committee (DoD, 2011). In assessing whether a technology has reached a certain maturity level, and when comparing the maturity of different technologies, one also needs to consider whether that specific technology is in operation under existing permits or other approvals. A history of successful permitting or approval may provide some confidence that the emplacement and operation of the technology at a different site will be successful.

Data from a demilitarization technology with a proven track record may also enable a more accurate cost estimate as well as an estimate of the throughput rate when processing a given type of munition.

PERMITABILITY AND OTHER APPROVALS

Permitability is the ability, or expected ease, to permit an alternative technology under applicable federal, state, tribal, and local laws and regulations. This criterion also includes other approvals, as not all technologies will require permits. There are also instances where alternative technologies may be exempt from RCRA permitting based on the RCRA regulations applicable to a given treatment process (e.g., recycling or certain RCRA exemptions). However, a declaration of exemption from RCRA can also require an application and approval, and the facility may need other permits (e.g., Clean Air Act [CAA]).

The most significant law for the demilitarization of conventional munitions is RCRA (see Chapter 6). The RCRA regulations applicable to an alternative technology depend on the type of technology used to treat the conventional munition or munition component. RCRA regulations focus on protecting human health and the environment based on risks from exposures to contaminants in the air, surface and groundwater, or soil. In addition, there may be other permits required when permitting an alternative technology unit, including the CAA, the Clean Water Act, water use laws, or other cultural and natural resources laws.

Several factors can impact permitability or other approvals. First, as a practical matter, an alternative treatment technology is more likely to be permitted or otherwise approved in a more efficient manner if that technology has been permitted or approved at similar locations and for the treatment of the same or similar wastes. Similarly, the more mature the munition access, treatment, and pollution control technology, the more data are available and, again, the more likely the process will be permitted or otherwise approved in a more efficient manner.

Also, public opposition can impact permitability or approvals by lengthening the permitting process or by asking regulators to impose operational conditions, health risk studies, and other conditions on OB/OD or the alternative technology permits.

MONITORABILITY

It is important that any treatment method can be monitored accurately for both emissions and completeness of treatment. In terms of monitoring emissions, treatment methods need to allow for the effective monitoring of pollutants of concern in all waste streams to determine, for example, if air pollution abatement systems are performing as designed, or if liquid or solid secondary wastes need specific treatment before their disposal. Furthermore, monitoring of surrounding soil, water, and air for pollutants that might be emitted during demilitarization activities may be necessary based on permit or other requirements. Monitoring of soil and groundwater can support rapid corrective action and significantly reduce closure costs. Monitoring for ambient air pollutants (associated with the demilitarization technology) is key to ascertain whether the demilitarization activity could affect public health.

Although costly and a negative impact on throughput, some technologies allow for holding a waste stream for monitoring or testing before it is released. This can be done for solid, liquid, and gas streams. However, hold, test, and release is usually applied to treatment of chemical weapons due to the toxicity of the chemical warfare agents.

Last, any demilitarization technology would ideally allow for a post-treatment inspection and testing of the munition or treated residue to determine that explosives and or propellants have been sufficiently treated, to allow for disposal or recycling.

PUBLIC CONFIDENCE

Experience has shown that building public confidence and trust via public consultation and participation in the technology selection process is instrumental (it will promote legitimacy); substantive (it will lead to better decisions); and normative (it is the right thing to do in our society; see Fiorino, 1989, and NRC, 2008). A lack of public confidence can impact schedules, cost, and ultimately, the implementation of technologies. Also, as noted earlier, public opposition can cause delays in the permitting process and influence the permit conditions imposed on alternative technology implementations.

Public confidence in a technology and related program management can be linked to core questions, such as "how safe is safe enough," and cannot solely be answered by science nor technology; they are questions of human values (NRC, 1996). These values, along with social trust, are key factors shaping both management and public perceptions of technologies, including (of relevance to this study) the selection and prioritization of criteria that are used to evaluate them. For example, if the public conceives that some variables are weighted more heavily in the decision-making process than those that are a priority for them (e.g., public health or environmental impacts), public confidence could be undermined.

To evaluate public confidence in making decisions on alternative technologies, the committee considered the following factors:

- The characteristics of a technology and associated risks (e.g., the potential for catastrophic releases, familiarity of technology and risks, types of secondary wastes generated, distribution of risks and benefits within and among communities);
- The management of the technology (e.g., information is publicly available about how the technology and its pollution abatement system work, monitoring data are immediately available and accessible); and
- The processes for making decisions (e.g., are they viewed as being fair, transparent, based on accepted and appropriate criteria).

REFERENCES

DoD (Department of Defense). 2011. Technology Readiness Assessment (TRA) Guidance. https://www.acq.osd.mil/chieftechnologist/publications/docs/TRA2011.pdf.

Fiorino, D.J. 1989. Technical and democratic values in risk analysis. *Risk Analysis* 9(31):293-299.

NRC (National Research Council). 1996. *Understanding Risk: Informing Decisions in a Democratic Society*. Washington, D.C.: National Academy Press.

NRC. 2008. *Public Participation in Environmental Assessment and Decision Making*. Washington, D.C.: The National Academies Press.

SEC. 1421. 2016. Alternative Technologies for Munitions Disposal, National Defense Authorization Act for Fiscal Year 2017. 2000; Public Law 114-328. https://www.congress.gov/bill/114th-congress/senate-bill/2943/text.

6

Regulatory Requirements Applicable to Open Burning, Open Detonation, and Alternative Technologies

The primary regulatory programs governing the treatment of conventional munitions—whether open burning (OB), open detonation (OD), or alternative technologies—is the Resource Conservation and Recovery Act (RCRA) permitting program[1] and the Clean Air Act (CAA) program.[2] Under RCRA, hazardous waste treatment, storage, and disposal facilities (TSDFs) used to demilitarize waste munitions are required to obtain, after notice and public comment, permits that establish specific operating conditions, as well as the requirements for facility closure. The RCRA Military Munitions Rule (MMR) is specifically applicable to unused conventional munitions and how they are designated as hazardous waste, stored, and transported under RCRA. (For more information on the Military Munitions Rule, see Appendix C.)

While RCRA is a federal program, each of the seven states that have jurisdiction over Army stockpile depots are authorized by the Environmental Protection Agency (EPA) to implement RCRA permitting and compliance. States may impose more stringent requirements than those found in federal regulations. Six of the seven Army OB/OD facilities have been issued final permits.[3] The Blue Grass Army Depot (BGAD) still has an interim status under RCRA for its OB/OD units.[4] Interim status allows the facility to operate until the state issues its final ruling on the facility's Part B RCRA permit application.[5]

Alternative technology units at the seven Army stockpile depots also are permitted under RCRA. Many are permitted as miscellaneous Subpart X units, although some thermal treatment technologies meet the regulatory definition of, and are permitted as, incinerators.[6] Some alternative technologies may fall under certain RCRA TSDF permitting exemptions. Table 6.1 shows the existing permitted alternative technology units.

OB/OD and alternative technology units may be subject to permitting under CAA, which governs air emissions from certain types of facilities. The applicability of CAA regulations will depend on the type of emissions associated with the unit. To prevent duplication of regulatory jurisdiction, RCRA permits may include air emission controls.[7] However, certain facilities (including incinerators) that emit listed hazardous air pollutants are required to meet air pollution control standards that apply maximum achievable control technology (MACT). These facilities require separate CAA Title V permits. Depending upon the emissions, alternative technologies may also be required to meet alternative specific MACT requirements. Since there is no national industry category for these alternative technologies, the MACT requirements will need to be established through a resource intensive process on a case-by-case basis.

In addition, OB/OD units and alternative technology units may be subject to permitting or restrictions under the Clean Water Act. The Clean Water Act governs discharges of wastewater into streams, rivers, lakes, and oceans, as well as run-off. Permits or similar approvals may also be required under state and local water-use laws, noise and odor regulations, and cultural and natural resources laws.

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[1] 42 U.S. Code §6901 et seq; Code of Federal Regulations (CFR) at 40 CFR §§260 to 272.

[2] 42 U.S. Code §7401 et seq; 40 CFR Parts 50-98.

[3] 40 CFR 264.

[4] 40 CFR 265.

[5] 40 CFR 270, Subpart G, and 40 CFR 265.

[6] The permitting state determines whether a TSDF unit is governed by Subpart X provisions because it does not meet the definition of other types of specifically permitted units, including incinerators (Subpart O), surface impoundment (Subpart K), waste pile (Subpart L), land treatment unit (Subpart M), landfill (Subpart N), or a boiler or industrial furnace.

[7] 40 CFR 264 and Part 265, Subparts AA, BB, and CC. 40 CFR 60, Parts 60, 61, and 63.

APPLICATION OF RCRA TO OB/OD AND ALTERNATIVE TECHNOLOGIES

The EPA's initial hazardous waste permit regulations, issued in 1980, banned the OB and OD of hazardous wastes,[8] except for waste explosives, which include "waste which has the potential to detonate and bulk military propellants which cannot be safely disposed of through other modes of treatment."[9] The EPA found that "waste explosives and bulk propellants are inherently dangerous to cut or disassemble to make them amenable to present thermal treatment technologies and that open burning and open detonation of known types of and amounts of bulk propellants and explosives can be conducted safely without harm to human health and the environment."[10] The 1980 permitting regulation allows the OB and OD of waste explosives, within specified distance and weight limitations, during the interim status permitting period.[11] In 1987, the EPA concluded that facilities conducting OB/OD of waste explosives would receive permits under the RCRA Subpart X provisions as miscellaneous units.[12]

RCRA regulations establish specific conditions for certain TSDF technologies, including incinerators; thermal treatment; chemical, physical, and biological treatment; land treatment; landfills; and surface impoundments. In those situations where a treatment process does not meet the definition under any of these specific technologies, EPA or an authorized state permits the technology as a miscellaneous unit, often referred to as Subpart X.[13] Subpart X regulations govern the location, design, construction, operation, maintenance, and closure of these treatment facilities.[14] Most alternative technology facilities (except for incinerators) are designated as miscellaneous units under Subpart X (see Table 6.1).

Rather than establishing specific regulatory permit conditions for testing, emissions control, and operations for a wide variety of miscellaneous treatment technologies, the RCRA Subpart X regulations require that miscellaneous units "must be located, designed, constructed, operated, maintained, and closed in a manner that will ensure protection of human health and the environment, including, but not limited to, as appropriate, design and operating requirements, detection and monitoring requirements, and requirements for responses to release of hazardous waste or hazardous constituents from the unit."[15]

Two EPA regions have issued draft guidance for permitting Subpart X units, but none of these regional guidances were finalized (EPA, 2002; Tetra Tech, 2002). However, state environmental agencies are not required to include or enforce permit conditions suggested in EPA guidance in general and regional guidance in particular.[16] Since there is no final, nationwide EPA guidance or regulation concerning what risk goals should be applied to ensure protection of human health and the environment for Subpart X units, states with jurisdiction over the seven stockpile depots may apply different risk goals based on state laws, regulations, and policies. Therefore, each state's permit writers must follow state law and regulations and typically review and assess scientific information, policies, and legal requirements each time a Subpart X permit is being developed for an alternative technology, resulting in duplication of effort by the Army and the state and possible conflicting outcomes for similar facilities. The lack of specific detail in the regulations concerning technical permitting requirements for Subpart X facilities places the burden on state regulators to devise technology- and site-specific requirements for OB/OD and for the wide range of alternative technologies discussed in this report, yet with fewer resources than are typically available for the promulgation of a national regulation by the EPA.

Generally, the EPA uses risk ranges of between 1 in 10,000 and 1 in 1 million for incremental lifetime cancer risk to determine whether a regulatory action is needed to protect human health (GAO, 2000).[17,18] Many of the states that have granted RCRA OB/OD Subpart X miscellaneous

[8] 40 CFR 260.10—Open burning is defined as the combustion of any material without the following characteristics: (1) control of combustion air to maintain adequate temperature for efficient combustion; (2) containment of the combustion reaction in an enclosed device to provide sufficient residence time and mixing for complete combustion; and (3) control of emission of the gaseous combustion products.

[9] 40 CFR 265.382.

[10] 45 Federal Register 33063-33285, p. 33217, May 19, 1980.

[11] 45 Federal Register 33063-33285, p. 33217, May 19, 1980.

[12] 52 Federal Register 46.946, 46.949-50, 46.957-58 (December 10, 1987).

[13] 40 CFR 264, Subpart X, 264.600-603.

[14] 40 CFR 264.601.

[15] 40 CFR 264.601.

[16] For example, the Seventh Circuit ruled that "Region V is not the 'Administrator' [of EPA]. Its policy statement is a go-it-alone document separate from the Administrator's advice to the states. Unless the Administrator later applies the policy statement to a plant, nothing will come of it." American Paper Institute, Inc., Petitioner, v. United States Environmental Protection Agency, Respondent, 882 F.2d 287 (7th Cir. 1989), https://law.justia.com/cases/federal/appellate-courts/F2/882/287/207683/. Furthermore, the court noted, "[n]either Region V nor the Administrator 'promulgated' anything. Promulgation means issuing a document with legal effect. Region V's policy statement has none: it does not appear in the Federal Register and will not be codified in the Code of Federal Regulations." Brock v. Cathedral Bluffs Shale Oil Co., https://openjurist.org/796/f2d/533/brock-v-cathedral-bluffs-shale-oil-co.

[17] EPA (2002) states that if the cancer and non-cancer risks calculated using site-specific data and modeling are below certain screening levels no further evaluation is necessary. These screening levels are defined as exposure that corresponds to a 1 in 100,000 ("10^{-5}") lifetime cancer risk for exposure at the fenceline and, for non-cancer risks, a screening level risk measured by a hazard index (i.e., the ratio of the calculated exposure to an exposure level that is unlikely to present a significant non-cancer risk). If these screening levels are exceeded, "the site should be assessed through a detailed risk evaluation."

[18] EPA's 2002 Region III "Draft Final Open Burning/Open Detonation Permitting Guidelines" (EPA Region III Draft OB/OD Guidance), written specifically for Subpart X applicants in the state of Virginia, uses somewhat different risk screening values based on Virginia regulations.

TABLE 6.1 RCRA-Permitted Alternative Technologies at Army Stockpile Facilities

Technology	Army Facility	Permitting State	Permit
Deactivation furnace (APE 1236)	TEAD, MCAAP, CAAA	Utah, Oklahoma, Indiana	Subpart O, Incinerator
Ammonium perchlorate rocket motor destruction facility (ARMD)	LEMC	Pennsylvania	Subpart X, Miscellaneous unit
Disassembly line (primers from small-caliber munitions)	TEAD	Utah	Subpart X, Miscellaneous unit
Static Detonation Chamber	ANMC	Alabama	Subpart X, Miscellaneous unit
Thermal treatment closed disposal process (TTCDP)	ANMC	Alabama	Subpart X, Miscellaneous unit
Plasma Ordnance Demilitarization System (PODS) incinerator[a]	HWAD	Nevada	Subpart O, Incinerator
Bulk Energetics Demilitarization System (BEDS) incinerator[a]	HWAD	Nevada	Subpart O, Incinerator
Hazardous waste incinerator (rotary kiln incinerator and combustion chamber; RF-9)	HWAD	Nevada	Subpart O, Incinerator
Confined Detonation Chamber	BGAD	Kentucky	Other Process (X99)
Molten salt destruction unit[a]	BGAD	Kentucky	Other Process (X99)
Flashing furnace system	BGAD	Kentucky	Other Process (X99)
Wash-out building	BGAD	Kentucky	Other Process (X99)
Industrial supercritical water oxidation (iSCWO) system [a]	BGAD	Kentucky	Other Process (X99)

[a] Not currently constructed or not in use.

NOTE: ANMC, Anniston Munitions Center; BGAD; Blue Grass Army Depot; CAAA, Crane Army Ammunitions Activity; HWAD, Hawthorne Army Depot; LEMC, Letterkenny Munitions Center; MCAAP, McAlester Army Ammunition Plant; TEAD, Tooele Army Depot.

unit permits for the Army stockpile depots have relied on the best available OB/OD emission factor database, a compilation of numerous OB/OD emission tests within an enclosed chamber (i.e., the BangBox emission tests), which the EPA has validated for setting OB/OD permit restrictions (Mitchell and Suggs, 1998). Or, for example, for the Anniston Army Depot (ANAD) permit, the state required that the cumulative incremental cancer risk posed by the Anniston Chemical Agent Disposal Facility and ANAD's OB, OD, and Static Detonation Chamber (SDC) units must be below 1 in 10^{-5} to protect human health.[19]

Some state permits impose environmental and operational limits for Army Subpart X units based on dispersion modeling. For example, the 2008 Tooele Army Depot (TEAD) permit[20] cited modeling results from the Multimedia Environmental Pollutant Assessment System,[21] which indicate that, based on several conservative and upper end exposure assumptions, the concentrations of constituents of concern released through groundwater leaching, overland runoff, surface water recharge, and atmospheric deposition from open detonation are expected to be lower than the health-based concentration limits.

RCRA permit applications for alternative technology units under Subpart X will also require information on the potential pathways of exposure of humans and the environment to hazardous wastes or hazardous constituents and on the potential magnitude and nature of such exposures.[22]

[19] ANAD Hazardous Waste Facility Permit, AL3 210 020 027, issued November 14, 2007, Module V.G. Air Monitoring (Mod 22). Similarly, risk estimates at the Utah Test and Training Range of 5 in 1 million, were "within the general risk acceptance limits," and risks of 1 in 10,000 were considered acceptable. Submission to State of Utah, Attachment 10b: Thermal Treatment Unit Human Health Risk Assessment (2013), https://deq.utah.gov/businesses/U/utahtestrange/docs/2013/08Aug/Attachment_10B_Human_Health_Risk.pdf. Also see BAE Systems, Ordnance Systems, Inc., and Coterie Environmental, Multipathway Risk Assessment Protocol for the Radford Army Ammunition Plant Open Burning Grounds (October 2015), Open Burn/Open Denotation (OB/OD) operations at the Utah Test and Training Range (UTTR)-North at 10B-17 (October 2015), http://www.deq.virginia.gov/Portals/0/DEQ/Land/Radford/OBG_Risk_Assessment_Protocol.pdf.

[20] Hazardous Waste Permit, Tooele Army Depot, UT3213820894, Attachment 1—General Facility Description, May 2008.

[21] The Multimedia Environmental Pollutant Assessment System is a Pacific Northwest National Laboratory suite of environmental models to assess environmental contamination problems, integrating transport and exposure pathways for chemical and radioactive releases to determine their potential impact on the surrounding environment, individuals and populations. See https://mepas.pnnl.gov/mepas/.

[22] 40 CFR 264.601.

These assessments can be based on site-specific modeling, scientific investigation, and actual data from similar operating units with similar waste streams in lieu of performance testing. If the unit is considered a combustion unit (e.g., an incinerator), it must comply with the EPA Human Health Risk Assessment Protocol[23] to develop and submit a human health and environmental risk assessments.

Permit Limitations

The RCRA permits for the seven Army stockpile sites contain specific limitations on demilitarization operations that may affect destruction flexibility and throughput. Permits for OB/OD units typically include limitations such as the type of munitions that can be treated, the total net explosive weight (NEW) treated, the hazard class,[24] atmospheric conditions, time of day, and specific equipment or procedures to employ. Examples of types of munitions that often cannot be treated under existing OB/OD permits include chemical warfare agents, smokes, incendiaries, and radioactive materials (e.g., depleted uranium). In addition, a few permits specify that only certain munitions may be treated in the unit—for example, only rocket and missile motors can be treated in the Letterkenny Munitions Center Open Burn Unit 2. Almost all OB/OD permits limit the amount of NEW that can be treated at any one time. For example, the permit may limit operations to a maximum NEW per burn pan per day, a maximum NEW per burn event, a maximum NEW per detonation with a specific number of detonations per day, or a total NEW burned per day or per year.

Permits may designate that OB/OD operations can take place only during certain atmospheric conditions. For example, some permits limit when OB/OD operations may occur to daylight hours, when meteorological data show moderate wind speeds are between 3 and 20 miles per hour, when storms or precipitation events are not expected, when cloud cover is less than 80 percent and ceilings greater than 2,000 ft.,[25] or when wind direction will not carry emissions over any publicly accessible area within 1 mile of the unit boundary.[26]

OB/OD permits may require that certain equipment be employed, including metal burn pans with covers, stands, or cages. Also, specific Army standard operating procedures (SOPs) designating how each OB or OD event is to be conducted may be incorporated into the permit, thus becoming enforceable requirements. Permits for OB/OD units often include certain environmental requirements, such as soil monitoring or runoff controls.

Permits for alternative technologies may have limitations on operations similar to those on OB/OD that can impact flexibility and throughput. For instance, the Ammonium Perchlorate Rocket Motor Destruction facility at the Letterkenny Munitions Center is limited to a maximum daily amount of propellant of 32,100 lb NEW, based on the largest motors to be treated. The maximum number of motor firings per day is dependent upon the size of the rocket or missile motors to be fired that day; however, the permit states that the number of firings per day shall not exceed 60.[27] The permit for the deactivation furnace (the APE 1236) at TEAD imposes operating requirements and feed rate limits—for example, the total propellant, explosive, and pyrotechnics feed rate must be less than 229 lb per hour.[28]

In addition, the permits for alternative technologies will also typically limit the types of munitions that can be treated to only specific munitions or to only munitions that have been approved by the state based on hazardous waste characterization protocols. Some of these limitations are based on technology limitations, but some may be the result of (1) how the original RCRA application was worded or (2) availability of RCRA waste characterizations for a variety of munitions. The permits for incineration units usually impose monitoring requirements for emissions from the pollution abatement system equipment, munition feed rates, and other waste analysis data. None of the current permits for alternative technologies for the demilitarization of conventional munitions requires holding and testing of emissions before release. Unlike an OB/OD permit, the permits for alternative technology units generally do not have limitations based on atmospheric conditions. In addition, they do not typically require extensive monitoring of surrounding environmental media since the units typically are enclosed.

Public Involvement

Public involvement can have a significant impact on the permitting of any demilitarization technology by extending comment and hearing periods under RCRA and through the potential for legal challenges to permits. RCRA permitting regulations require public participation activities during the permitting process and during the life of the permit. Under the expanded public participation rules, the permit applicant must host an informal, public preapplication meeting before submitting the Part B RCRA permit application. As recommended by the EPA, public comments and suggestions are easier for the facility to address earlier rather than later in the process, so public input can have greater impact at this preapplication stage.[29]

[23] EPA, Final Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, EPA530-R-05-006, September 2005.

[24] 49 CFR 172.50.

[25] TEAD Hazardous Waste Facility Permit, UT3213820894, attachment issued February 2, 2017.

[26] ANAD Hazardous Waste Facility Permit, AL3 210 020 027, issued November 14, 2007.

[27] Letterkenny Army Depot Hazardous Waste Permit modification, PA6213820503, dated December 8, 2014.

[28] TEAD Hazardous Waste Facility Permit, UT3213820894, Module IV, Incineration, issued February 2, 2017.

[29] EPA, Resource Conservation and Recovery Act Public Participation Manual, January 11, 2017, 530-R-16-013.

In addition, the regulator must create a representative facility mailing list of those to receive notifications during the permitting process.[30] The permitting agency also may require the facility owner/operator to establish an information repository. The permitting agency also can share information with the public and hold workshops or other public meetings to provide fact sheets and other information to the community. During the complex permit decision process, open lines of communication to keep the public involved and informed may take additional effort.

Last, the permitting agency must notify the public of its decision, either the intent to deny the application or by issuing a draft permit, including a fact sheet and statement of basis. Once the decision is issued, there is at least a 45-day public comment period, and, if requested by the public or applicant or at the state regulatory agency's discretion, a public hearing will be held with 30-day advance notice. The EPA recommends permitting agencies prepare a public participation plan for controversial facilities, possibly including hotlines, news releases, websites, and social media posts.[31] The permitting agency must prepare a response to comments document to address all significant comments raised during the public comment period. Any modifications to a permit have similar public notice and participation requirements, depending on the class of the modification.[32]

Comments and written documents submitted to the committee by public interest groups and members of the public highlight a set of concerns about OB/OD and alternative demilitarization options that could be raised during the permitting, renewal, or modification process[33] (see Chapter 9, Appendix B, and Appendix D.)

TREATMENT UNITS EXEMPT FROM RCRA PERMITTING REQUIREMENTS

As discussed by several presenters, including the EPA,[34] some alternative technology units may not need an RCRA TSDF permit. For example, an alternative pyrolysis technology (Decineration; see Chapter 4) operates pursuant to an Indiana Department of Environmental Management letter of determination that no RCRA TSDF permit is required because the process would be considered materials recovery under the MMR,[35] as long as Indiana's standard for scrap metal contaminated with hazardous waste residue is met.[36] Another example of exempt treatment technologies is the nonthermal treatment (e.g., neutralization) of wastes while the wastes are being accumulated in the waste generator's tanks or containers.[37]

Obtaining a determination that an alternative technology meets the definition of an existing exempt process would reduce the time to construct or install alternative technology units at Army munition demilitarization facilities. However, obtaining a ruling or letter determination from a state environmental agency for a new process still could take time and substantial data submissions to ensure that the process or technology meets the definition of an exempt unit and any other environmental standards applicable under RCRA or other environmental programs (e.g., CAA). Exempt treatment processes, depending on the technologies used, will generally require other state permitting or regulatory oversight with site-specific operational restrictions (e.g., wastewater or storm water discharge permits, or water use permits).

TREATMENT, STORAGE, AND DISPOSAL FACILITY (TSDF) CLOSURE

All RCRA permitted units are required to plan for and complete closure at the end of their life cycle—that is, the last step in the use of the property is determining the extent of contamination and remediating any contamination to environmental standards. All TSDFs, including Subpart X units such as OB/OD units and alternative technologies, are required to submit a closure plan as part of their permit application.

The premise of clean closure is that all hazardous wastes have been removed and any releases at or from the unit have been remediated so that further regulatory control under RCRA is not determined to be necessary to protect human health and the environment. Clean closure may leave in place some contaminated environmental media if they are below concentrations levels that may pose a risk to human

[30] 40 CFR 124.10.

[31] EPA, Resource Conservation and Recovery Act Public Participation Manual, January 11, 2017, 530-R-16-013.

[32] 40 CFR 270.42.

[33] The committee received comments from the CeaseFire! Campaign, which is a national-level public interest group comprising a coalition of more than 60 local groups, and from several members of the public.

[34] E-mail from Sasha Gerhard to the Committee. Subject: EPA follow-up items for NASEM CMD committee, sent November 22, 2017.

[35] Under the MMR, unused munitions that are repaired, reused, recycled, reclaimed, disassembled, reconfigured, or otherwise subjected to materials recovery activities are not solid waste and would not require a RCRA TSDF permit. 40 CFR 266.202(a)(2).

[36] Indiana Department of Environmental Management, Letter Re: U.S. Demil, LLC, Military Munitions Project, Crane Surface Warfare Center, IN5170023498, June 14, 2016.

[37] 51 Federal Register 10146, 10168, March 24, 1986. EPA ruled that hazardous waste generators could treat hazardous wastes on-site in accumulation tanks or containers without an RCRA permit if the treatment were in conformance with the requirements of 40 CFR Part 262.34 (accumulation time) and with Subparts I and J of 40 CFR 265 (standards for containers and tank system, including that the tanks or containers in which the treatment occurs remain closed except when adding or removing waste, the process must not violate the dilution prohibition standards of 40 CFR 268.3 and must meet any applicable land disposal restrictions (40 CFR 268.7(a)(4)).

health and the environment.[38] For Subpart X miscellaneous units, clean closure requires that environmental performance standards found in the regulations be met,[39] including prevention of any releases that may have adverse effects on human health or the environment due to migration of waste constituents into the groundwater or subsurface environment. This is determined either through risk assessment or by using available constituent-specific limits or factors that have undergone regulatory review (e.g., maximum contaminant levels for water or a verified reference dose). Closure provides that interim measures be implemented to ensure that protection of human health and environment is maintained during the implementation of the clean closure.[40] Typically, clean closure costs should be included in the LCC cost analysis of the treatment unit (see Chapter 9).

CHANGING REGULATORY ENVIRONMENT

The Government Accountability Office found that regulator's environmental concerns with OB/OD may force the Department of Defense (DoD) to use alternative methods of disposal in the future (GAO, 2000). The EPA staff presentation to the committee included a recently initiated project to identify alternatives to OB/OD.[41] This project apparently will assess technologies and streamlining procedures and permitting, which will document the existence of alternative technologies and provide information on feasibility, cost, and cost-effectiveness of these alternatives.[42] The EPA provided a draft Alternate Technology Matrix and Compilation Report to the committee, which the committee considered in its independent evaluation of alternative technologies.[43] At least one state representative (from the Alabama Department of Environmental Management) also expressed to the committee an unwritten preference to consider more alternative technologies to replace OB/OD. However, two authorized state environmental agencies with jurisdiction over Army stockpile OB/OD facilities stated to the committee that there is no current state regulation or official policy that promotes the use of alternative technologies in lieu of OB/OD.[44]

At least one state, Utah Department of Environmental Quality, has required the Army to maintain a certification that treatment of waste munitions by OB/OD is the only practicable method or combination of methods currently available to minimize the present and future threat to human health or the environment and that TEAD has a program in place to investigate available alternative technologies, other than OB and OD, to reduce the volume and toxicity of released treatment residues and discharges to the environment.[45] In filings with the state of Utah, the Army indicated that the reasons for continued use of OB/OD are cost; the lack of organic, omnivorous on-site facilities; and the need to disassemble munitions to meet the technical requirements for alternative technologies, resulting in increased personnel handling.[46]

Another state, New Mexico, has denied the Department of Energy (DOE) an RCRA TSDF permit for a non-Army OB/OD treatment unit at the Los Alamos National Laboratory because (according to the state's final decision) continued OB of high-explosive hazardous waste would result in an ecological risk, 1,400 individuals had expressed opposition to continued OB in comments submitted during the public comment period, the New Mexico Environmental Department did not believe that the applicants adequately assessed alternatives to OB that would be more protective of human health and the environment, and there were preferable and viable alternatives to OB of high-explosive waste at the laboratory (NMED, 2010).

While regulators' perceptions of OB/OD and alternative technologies appear to be evolving, there are no federal written policies or RCRA regulations stating such a preference. It is also important to note that all existing Army stockpile depot OB/OD TSDFs are permitted by, or hold RCRA interim status from, an authorized state and were found by the regulatory authority to be protective of the human health and the environment. This evolving regulatory environment may have a significant impact on whether the stockpile sites continue to utilize OB/OD or on the ease with which an alternative technology can be permitted under RCRA.

Finding 6-1. There is no formal EPA guidance for permit applicants or authorized state agencies to determine the

[38] The EPA has stated that in order to demonstrate clean closure, the owner and operator must show that levels of hazardous contaminants do not exceed EPA-recommended exposure levels, or clean closure levels. EPA has not specified contaminant levels for clean closure. "How clean is clean" is a site-specific decision made by the EPA region or authorized state. Limited amounts of hazardous constituents may remain in media after clean closure, provided they are present at concentrations below which they may pose a risk to human health and the environment. The implementing agency can identify clean closure based on established, protective, risk-based levels (e.g., maximum contaminant levels under the Safe Drinking Water Act), or site-specific risk-based levels (EPA, 2005).

[39] 40 CFR 264, Subpart G

[40] 40 CFR 264, Subpart G.

[41] K. Shuster, presentation to committee, "Alternatives for the Demilitarization of Conventional Munitions," dated August 22, 2017 and follow-up data request responses via e-mail dated November 22, 2017.

[42] Ibid.

[43] EPA Draft Alternative Technologies to the Open Burn and Open Detonation of Energetic Hazardous Wastes, dated October 19, 2017; Draft Alternative Technologies to the Open Burn and Open Detonation of Energetic Hazardous Wastes Workbook/Matrix, received October 19, 2017; EPA Draft Alternative Tech Not Going Forward, received November 17, 2017.

[44] L. Houseal, Pennsylvania Department of Environmental Protection, "Pennsylvania Regulatory Perspectives," presentation to the committee, December 11, 2017. S. Cobb, chief, Land Division, Alabama Department of Environmental Management, "Alabama Regulatory Perspectives," presentation to the committee, December 11, 2017.

[45] TEAD Hazardous Waste Facility Permit, UT3213820894, Condition II.M.2, issued September 30, 2005. Also, see letter certifications filed with the Utah Department of Environmental Quality dated January 14, 2014, January 7, 2016, and January 10, 2017, respectively.

[46] TEAD RCRA Part B Permit Application, Attachment 21, OB/OD Treatment Effectiveness, Alternative Technologies and Waste Minimization, July 16, 2015.

requirements for applications or permit conditions (e.g., risk goals, treatment efficiencies, or waste and operational limitations) for alternative technology units that would be permitted as Subpart X units.

Finding 6-2. Provisions contained in permits for existing alternative technologies at Army demilitarization depots may limit the types of waste munitions that can be treated or the throughput of the units. Some of these limitations are based on the technology or regulatory limitations, but some may be the result of (1) how the original RCRA application was worded or (2) availability of RCRA waste characterizations for a variety of munitions.

Finding 6-3. Public interest group representatives express the need to consider community preferences and site-specific conditions when selecting an alternative technology to implement, install, and permit at any of the seven demilitarization depots.

Recommendation 6-1. The Army should investigate whether permits for existing alternative technology units at Army munition demilitarization depots can be amended to be more flexible regarding the types, frequency, and amounts of munitions that can be treated.

Recommendation 6-2. The Army should identify issues that could affect the Resource Conservation and Recovery Act permitting process for alternative technologies, including public concerns, and work with regulators in the states with jurisdiction over the seven demilitarization depots to establish requirements for Subpart X applications (e.g., developing scientific and technical analysis documents, emission modeling and estimates, and efficiency documentation for similar units) so as to address issues and questions before they become a problem that could significantly delay permitting alternative technologies.

REFERENCES

EPA (U.S. Environmental Protection Agency). 2002. Draft RCRA Miscellaneous Treatment Units, Encyclopedia X Technical Resource Document. EPA Region IV, RCRA Programs Branch. https://trainex.org/web_courses/subpart_x/Encyclopedia%20X%20pdf%20files/Draft_Encyclopedia%20X.pdf.

EPA. 2002. Draft RCRA Miscellaneous Treatment Units, Encyclopedia X Technical Resource Document. EPA Region IV, RCRA Programs Branch. https://trainex.org/web_courses/subpart_x/Encyclopedia%20X%20pdf%20files/Draft_Encyclopedia%20X.pdf.

EPA. 2005. EPA530-K-05-009. RCRA Training Module, Introduction to Closure/Post-Closure. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1008WG8.PDF?Dockey=P1008WG8.PDF.

GAO (Government Accountability Office). 2000. Precautionary Assumptions in Health Risk Assessments and Benefits Estimates at 12-13. http://www.gao.gov/assets/230/229762.pdf.

Mitchell, W.J., and J.C. Suggs. 1998. *Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation*. U.S. EPA, Research Triangle Park, N.C.

NMED (New Mexico Environment Department). 2010. State of New Mexico before the Secretary of the Environment, In the Matters of the Application of the United States Department of Energy and Los Alamos National Security, LLC for a Hazardous Waste Facility Permit for Los Alamos National Laboratory and the Notice of Intent to Deny a Permit for Open Burn Units TA-16-399 and TA-16-388 for Los Alamos National Laboratory, No. HWB 09-37(P)/HWB 10-04(P), Hearing Officer's Report, Santa Fe, N. Mex.

Tetra Tech. 2002. EPA Region III, Draft Final Open Burning/Open Detonation Permitting Guidelines. https://trainex.org/web_courses/subpart_x/TopicSearch%20pdf%20files/Region%203%20OBOD/PDF%206988-Text%20final.pdf.

7

Applicability of Treatment Types to Munitions and Energetic Types

For the purpose of evaluating alternative technologies to open burning (OB) and open detonation (OD), the committee found it useful to review and analyze possible alternatives for demilitarizing B5A (stockpile) account munitions in the following four categories

1. *Munitions that are already being demilitarized with alternatives to OB/OD*: These munitions are not directly addressed in this report as they are not included in the committee's statement of task. This category comprises all of the B5A munitions that are not included in any of the following three categories.
2. *Munitions that are suitable for OB/OD*: These munitions are discussed in the first section, below.
3. *Stable munitions that are being demilitarized using OB/OD but are suitable for demilitarization using alternative technologies*: These munitions receive a more detailed analysis in the second section, below, and in Tables 7.1 through 7.7.
4. *Munitions that are not being demilitarized using either OB/OD or alternative technologies*: This category of munitions constitutes "capability gaps" and are discussed in the third section, below. For the purposes of this report, the committee defines "capability gap" as "the inability to perform a demilitarization task on the 'top 400' munitions in the B5A account due to a lack of adequate equipment or processes."

MUNITIONS SUITABLE FOR OB/OD

Some munitions in the B5A account have been determined by the Office of the Product Director for Demilitarization (PD Demil) to be unstable and possibly shock sensitive owing to depletion of stabilizers in the explosives or propellants caused by excessive age. This makes them unsuitable for demilitarization using alternative technologies because transportation and handling must be minimized to reduce exposure of personnel to the explosive hazards posed by these munitions that may detonate or deflagrate when disturbed.[1] For these unstable munitions, the committee defers to the determination of PD Demil that movement and disturbance must be kept to the minimum amount necessary to achieve demilitarization and that OB/OD may be the most suitable demilitarization methods.

Only two munitions that are currently in the B5A account have been identified to the committee by PD Demil as not suitable for alternative contained demilitarization due to instability. According to PD Demil, the 105 mm rocket-assisted projectile (Department of Defense Identification Code [DODIC] C463 with a quantity of 240 tons) and 8 in. rocket-assisted projectile (DODIC D624 with a quantity of 744 tons) are potentially shock sensitive due to depletion of stabilizers in the rocket propellant. The committee accepts this determination and agrees that OD is the appropriate method for demilitarization of these munitions. The committee recognizes that other munitions may be added to this list in the future.

Finding 7-1. Alternatives to OB and OD are not being used for some munitions because the munitions have become unstable and are too hazardous for the handling and transportation required for demilitarization using alternative technologies. A determination by the PD Demil that a munition is unstable and potentially shock sensitive is a valid reason for performing demilitarization via OB/OD to minimize transportation and handling and, therefore, the exposure of technicians to the explosive hazard. The capability for OB/OD will always be needed.

[1] J.C. King, director for Munitions and Chemical Matters, HQDA, ODASA(ESOH), "DoD Open Burn and Open Detonation (OB/OD)," presentation to the committee, August 22, 2017.

MUNITIONS SUITABLE FOR ALTERNATIVE TREATMENT

PD Demil provided to the committee a list of the stable munitions in the stockpile that are being demilitarized by OB/OD, and the committee evaluated whether it is possible to demilitarize these munitions using the alternative technologies discussed in Chapter 4. This evaluation is presented in Tables 7.1 through 7.7, below. The committee offers these as examples of alternatives that may be applied. Note that munitions identified by PD Demil as "unstable" and possibly shock sensitive are not included in these tables.

Alternatives to OB/OD may require using multiple technologies in series (e.g., a treatment train), whereas OB/OD is more likely to provide for one-step demilitarization (e.g., by detonating large projectiles and bombs without disassembly or size reduction). Because of this, the examples of potential alternative technologies and processes in Tables 7.1 through 7.7 frequently involve several technologies in a treatment train.

An example of a treatment train is demilitarization of large, high explosive (HE)-filled bombs and projectiles. These munitions are too large to be contained by any of the existing contained detonation (CD) or contained burn (CB) treatment processes and, therefore, require "downsizing" through some type of munition size reduction procedure to prepare them for an alternative final demilitarization process.

Although there are some drawbacks to multistep demilitarization processes (e.g., potentially increased process complexity and increased munitions handling), such multistep processes should not be perceived as a barrier in that the technologies already exist and, in most cases, are currently being used at Army demilitarization depots and contractor facilities. For example, size reduction of large bombs and projectiles is currently being performed by PD Demil and contractors using band saws, waterjet cutters, and cryofracture before final demilitarization of the downsized components and HE in existing PD Demil and contractor facilities. [2] The committee also notes that "treatment trains" are commonly used in conjunction with OB/OD. For example, demilitarization of a fixed projectile may be accomplished through the multiple steps of separating (pulling) the projectile from the cartridge, emptying the propellant from the cartridge, and demilitarizing the propellant using OB and the projectile using OD. Therefore, "treatment trains" should be understood to be commonly used today and are not a barrier to implementing alternative technologies.

Another example of treatment trains being used to demilitarize similar munitions using both OB/OD and alternative technologies is the demilitarization of DODICs D563 and D864.[3] These two DODICs are variations of 155 mm projectiles loaded with scatterable submunitions (see Figure 7.1).

D563 is being demilitarized by PD Demil, using organic capabilities, by removing the submunitions from the projectile casing through disassembly and then disposing of them using OD. PD Demil then reuses the projectile casings by reloading them with new submunitions. Treatment of the similar DODIC D864 is being performed by a contractor. The contractor removes the submunitions from the projectile casings (as is done by PD Demil) and then disassembles the submunitions to prepare them for demilitarization by CB. In this example, final demilitarization of the similar submunitions from similar DODICs is being handled differently. PD Demil demilitarizes the submunitions using OD, while the contractor disposes of similar submunitions by disassembly followed by CB. It is possible to demilitarize both of these DODICs (two of the largest DODICs in the stockpile inventory) using existing alternative technologies that are fully developed and currently being implemented by the contractor.[4]

Another example of using existing alternative technologies in lieu of OB/OD is cutting shaped charges of high-explosive anti-tank (HEAT) munitions to defeat the shaped-charge effect followed by demilitarization of the prepared munition sections in existing CB systems. The reason given by PD Demil[5] for using OD for demilitarization of some HEAT munitions is that the munitions may cause damage to the incinerator from the shaped-charge effect in the event that the shaped charge functions inside the incinerator. However, presentations provided to the committee show that PD Demil contractors have solved this problem by using existing alternative technologies to cut the shaped charges to eliminate the shaped-charge effect, thereby allowing the "downsized" shaped charges to be demilitarized in existing CB facilities.[6]

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[2] J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee, August 22, 2017. H. Heaton, Dynasafe, "The Static Detonation Chamber and Conventional Demilitarization," presentation to the committee, October 23, 2017. P.L. Miller, Gradient Technology, "Abrasive Waterjet Cutting of Large Munitions," presentation to the committee, October 24, 2017. R. Hayes, president, El Dorado Engineering, "El Dorado Engineering's Technologies for the Demilitarization of Conventional Munitions," presentation to the committee, October 24, 2017.

[3] J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee on October 23, 2017.

[4] J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences, presentation to the committee, October 23, 2017. P.L. Miller, Gradient Technology, "Abrasive Waterjet Cutting of Large Munitions," presentation to the committee, October 24, 2017.

[5] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization by Open Burning and Open Detonation for National Academy of Sciences," presentation to the committee on December 11, 2017.

[6] H. Heaton, Dynasafe, "The Static Detonation Chamber and Conventional Demilitarization," presentation to the committee, October 23, 2017. R. Hayes, president, El Dorado Engineering, "El Dorado Engineering's Technologies for the Demilitarization of Conventional Munitions," presentation to the committee, October 24, 2017.

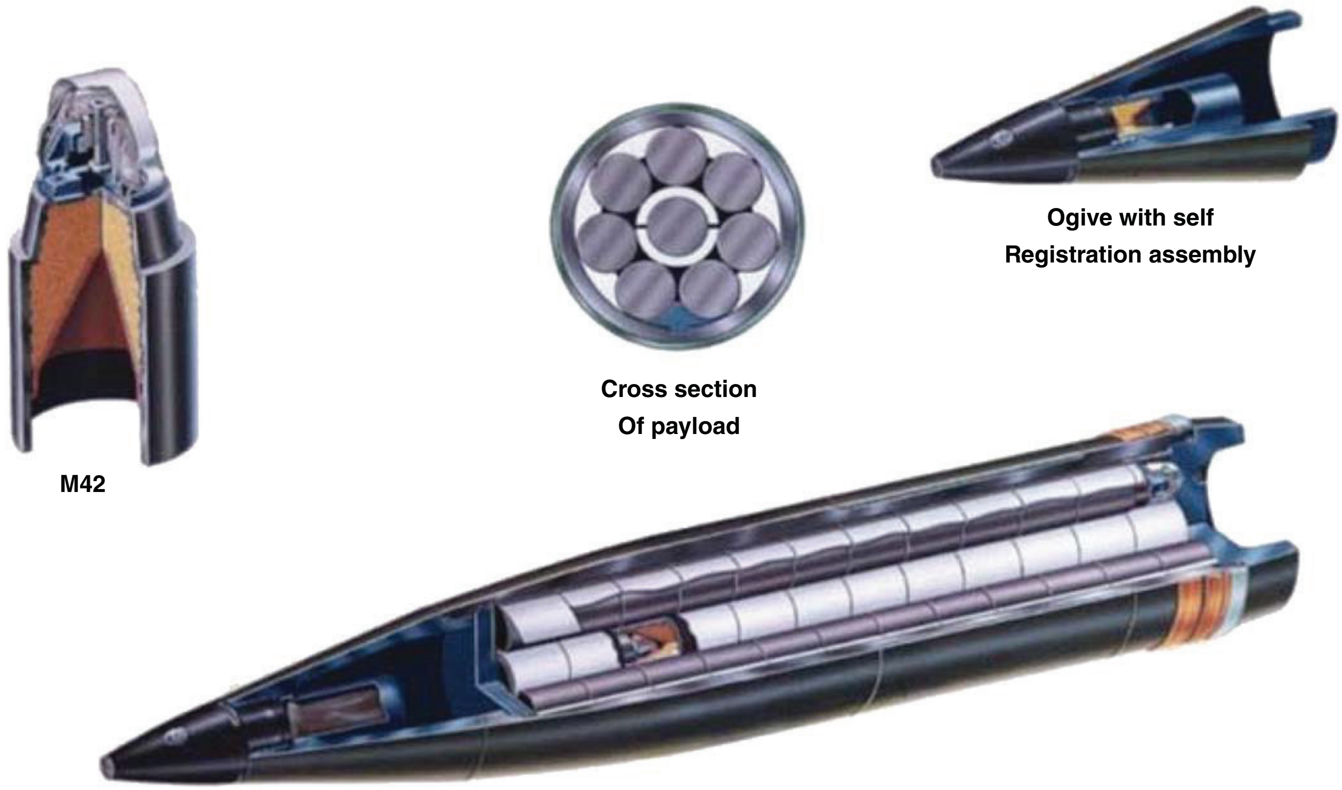

FIGURE 7.1 Cutaway of DODIC D563 projectile containing submunitions (grenades). SOURCE: J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization by Open Burning and Open Detonation for National Academy of Sciences," presentation to the committee, December 11, 2017.

Finding 7-2. The configuration of some munitions will require handling and processing steps prior to munitions demilitarization using alternative technologies. This adds complexity to the process, may increase the cost of demilitarization, and may increase risks to workers. These factors will have to be considered when evaluating the use of alternative technologies.

It is beyond the committee's capabilities to fully investigate whether or not existing alternative technologies are appropriate for every DODIC currently being disposed of by OB/OD, because that would require an in-depth technical and engineering analysis of the construction, fuzing, and functioning of each specific munition. However, based on the information presented to the committee by PD Demil and its contractors, it appears that, with few exceptions, it is technically possible to apply existing alternative technologies to demilitarize the majority of the DODICs in the stockpile inventory (with the previously described exception of those DODICs that have been determined by PD Demil to be potentially shock sensitive).

The committee believes that it may be possible to reduce demilitarization costs and the use of OB/OD by shipping stockpile munitions to other demilitarization facilities and notes that PD Demil is already shipping munitions for demilitarization. Examples of this are the rocket and missile motors being shipped to the Letterkenny Munitions Center (LEMC) Ammonium Perchlorate Rocket Motor Destruction (ARMD) facility[7] and the two new large contracts awarded to demilitarization contractors (Keller, 2015).

Finding 7-3. The organic capabilities of the PD Demil and the contractor community have the technical capability—or could develop the capability—to demilitarize nearly all of the munitions in the stockpile using alternative technologies. There will, however, always be some munitions that need to be treated by OB or OD for safety reasons.

Recommendation 7-1. In keeping with stated strategic goal to increase the use of contained disposal, resource recovery, and recycling consistent with continuing to ensure minimal exposure of personnel to explosive safety risks, the Office of the Product Director for Demilitarization should perform a detailed technical and engineering evaluation of the munitions in the inventory currently demilitarized by open burning or open detonation and evaluate appropriate alternative

[7] J. Wright, chief engineer, AMCOM Missile Demil, "Missile Demil Brief Static Fire for Rocket Motors to National Academies of Sciences Committee on Alternatives for the Demilitarization of Conventional Munitions," presentation to the committee, October 24, 2017.

demilitarization technologies for each munition along with an implementation schedule and budget requirements. This detailed evaluation should include the option of shipping munitions and munitions components to other organic or contractor facilities for demilitarization.

The committee analyzed the munitions in the demilitarization stockpile as of September 30, 2017, that (1) PD Demil identified as being disposed of by OB, OD, or static firing (a type of OB), and (2) have been determined by PD Demil to be stable (i.e., not shock sensitive due to deterioration of stabilizers). The committee then grouped these munitions into seven categories, based on common characteristics, and added an eighth group for miscellaneous munitions that do not share common characteristics with the other seven categories. Tables 7.1 through 7.7 identify the munition and DODIC, give example alternative demilitarization technologies, and provide some additional information, if applicable, including the reason given by PD Demil for not using alternative demilitarization technologies.

Please note that the purpose of these tables is to analyze whether or not potential alternative technologies exist that can be used for demilitarization of these munitions. The alternatives in these tables are presented as examples of possible alternative technologies that may be employed. They are not intended to be a definitive analysis or to discourage application of other alternative technologies that may be unknown to the committee or may be developed in the future

The committee evaluated the following munitions categories:

- Dispensers containing submunitions with shaped charges (both projectiles and bombs);
- HEAT projectiles;
- Gun propellant and rocket and missile motors;
- Mortars;
- HE projectiles, bombs, and rocket and missile warheads;
- Fuzes; and
- Miscellaneous munitions (those not fitting into one of the categories above).

The committee evaluated the suitability of demilitarizing the above munitions categories using the following alternative technologies, both separately and as part of a treatment train:

- Disassembly and separation of components;
- Size reduction to comply with net explosive weight (NEW) restrictions and to defeat shaped charges using manual or mechanical cutting, waterjet cutting, and cryofracture;
- Removal of explosives and energetics via washout and steamout;
- CB of explosive and energetic components;
- Contained detonation of explosive and energetic components; and
- Neutralization of explosive and energetic components.

TABLE 7.1 Stable[a] Dispensers with Shaped Charges (Projectiles and Bombs) Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes[c]
1. Cartridge, 105 mm HE APERS ICM, M444, DODIC C462, 5,100 tons	• Separate projectile from the propellant cartridge. • Demilitarize propellant in CB. • Disassemble the projectile or bomb to remove the submunitions. • Disassemble or cut the submunition shaped charges to disrupt the shaped charge effect. • Demilitarize the prepared submunitions in CB. • Recycle demilitarized components.	1. No notes
2. Dispenser and bomb, ACFT CBUI87B/B, DODIC E890, 1,855 tons		2. DODIC E890 is the only bomb in this group. As such, steps 1 and 2 are not required.
3. Projectile, 155 mm HEDP ICM APERS, M483A1, DODIC D563, 28,902 tons		3. DODIC D563 is similar to D864, which is already being demilitarized using this process. This DODIC includes internally loaded M42/M46 submunitions.
4. Cartridge, 105 mm HEAT-T-MP, M456/E1/A1/A2, DODIC C508, 686 tons		4. PD Demil says there is "no on-site capability" for alternative disposal of C508.
5. Cartridge and launcher, 84 mm M136 and AT4 Projectile, DODIC C995, 984 tons		5. DODIC C995 is a single-use recoilless rifle and projectile. PD Demil says disassembly of components exposes workers to excessive risk, so automation of this process may be required.
6. Projectile, 155 mm HEAT, M741 Copperhead, DODIC D510, 1,389 tons		6. For DODIC D510 PD Demil cites "unsafe to cut Comp B with saw," as the reason for not using alternatives. Using a different cutting technology (waterjet for example) may resolve this issue.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.
[b] Quantities are provided in gross tons, not NEW, [c] Numbered notes correspond to the numbered items in the first column.

TABLE 7.2 Stable[a] Gun Propellant Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes[c]
1. Charge, propelling, 155 mm WB M4 Series, DODIC D541, 2,041 tons	• Remove propellant from the bag or container if necessary. • Demilitarize loose propellant using CB.	1. PD Demil cites problem burning White Bag propellant in APE 1236 due to premature ignition of propellant.
2. Charge, propelling 155 mm WB, M119 series without primer, DODIC D533		2. No notes.
3. Charge, propelling, 8 in. WBM2, DODIC D676, 172 tons		3. No notes.
4. Reducer, flash M3F/8 in. propelling charge, DODIC D681, 439 tons		4. PD Demil cites safety issues dismantling this munition. However, it is 1 lb. of black powder and should be able to be demilitarized whole in an appropriate CB system.
5. Charge, 8 in. GB M1, DODIC D675, 94 tons		5. No notes.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.
[b] Quantities are provided in gross tons, not NEW, [c] Numbered notes correspond to the numbered items in the first column.

TABLE 7.3 Stable[a] Rocket Motors Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes
1. Rocket motor, 2.75 in. MK66-2, DODIC J147, 1,052 tons 2. Rocket motor, 2.75 in. MK40 Mod 5, DODIC J106, 214 tons 3. Rocket motor 5 -in. MK22-2/3/4F, Liner demo charge, DODIC J143, 191 tons 4. Rocket motor, Chaparral, DODIC V511, 229 tons	• Demilitarize rocket motors using static firing in CB containment. The Honest John, DODIC V511 may require downsizing to achieve NEW requirements for the Blue Grass Army Depot Controlled Detonation Chamber D-100. • Recycle inert components.	All of these rocket motors contain double-based propellant not suitable for demilitarization in the LEMC ARMD. PD Demil is considering the option of static firing in the Blue Grass Army Depot Controlled Detonation Chamber D-100.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.
[b] Quantities are provided in gross tons, not NEW.

TABLE 7.4 Stable[a] Mortars Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes
1. Cartridge, 60 mm HE M49A2/A4, DODIC B632, 2,074 tons 2. Cartridge, 81 mm HE M374 E1/A2/A3, DODIC C256, 641 tons 3. Cartridge, 81 mm HE M821, DODIC C868, 436 tons	• Remove propellant if necessary to meet NEW limitations. • Demilitarize propellant in CB. • Downsize (cut or cryofracture) mortar if necessary to meet NEW limitations. • Demilitarize mortar in CB. • Recycle inert components.	Mortars are being treated as a separate category because they come with their propellant rings wrapped around the tail boom and these may be removed (either by hand or by cutting the tail boom off) if desired and demilitarized by CB separately.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.

[b] Quantities are provided in gross tons, not NEW.

TABLE 7.5 Stable[a] High-Explosive Projectiles, Bombs, and Warheads Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes[c]
1. Cartridge, AF 30 mm HEI, PCU 13 BA/B Linked, DODIC B104, 288 tons 2. Warhead, 2.75 in. HE, XM/M151, DODIC H842, 2,153 tons 3. Bomb, GP 500 lb. MK82-1, DODIC E485, 2,240 tons 4. Projectile, 155 mm HE, M107 (TNT), DODIC D544, 164 tons	• Separate the propellant case from the projectile. • Remove and demilitarize the propellant in CB. • Reduce size of the projectile (sawing, waterjet, cryofracture). • Demilitarize projectile pieces in CB. • Recycle inert components.	1, 2, 3, and 4. Demilitarization of projectiles using alternative technology is being performed on a large scale on both small and large projectiles at Crane Army Ammunition Activity.
5. Cartridge, 105 mm TP-T, M490/E1/A1, DODIC C511, 127 tons 6. Cartridge, 90 mm canister, APERS, DODIC C601, 421 tons 7. Cartridge, 90 mm canister, APERS, M590, DODIC C410, 132 tons 8. Cartridge, 105 mm TPDS-T M724A1, DODIC C520, 278 tons		5, 6, 7, and 8. Have low NEW. PD Demil currently removes the projectile from the propellant casing and disposes of the propellant using OB.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.
[b] Quantities are provided in gross tons, not NEW, [c] Numbered notes correspond to the numbered items in the first column.

TABLE 7.6 Stable[a] Fuzes Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes
1. Fuze, PD M749/A1, DODIC N340, 1,559 tons 2. Fuze, PD, M557, DODIC N335, 1,551 tons 3. Fuze, MTSQ, M557/A1, DODIC N285, 1,227 tons 4. Fuze, M524 F/Mine AT M15, DODIC K068, 188 tons	• Direct demilitarization in an appropriate CB system.	All of these fuzes have small quantities of explosives and are suitable for direct demilitarization in an appropriate CB system. Many (thousands) of these fuzes have been demilitarized in the Anniston Army Depot Static Detonation Chamber.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.
[b] Quantities are provided in gross tons, not NEW.

TABLE 7.7 Stable[a] Miscellaneous Munitions Currently Demilitarized Using OB and OD and Example Applicable Alternative Technologies

Munition, DODIC, and Quantity[b]	Steps for Applicable Alternative Demilitarization	Notes[c]
1. Cartridge, Engine Starter MXU-4A/A, DODIC M158, 1,202 tons	• Disassemble or resize (saws, waterjet, or cryofracture) if necessary to meet NEW restrictions. • Demilitarize in an appropriate CB system.	1. Low NEW aircraft engine starter cartridge.
2. Charge assembly. Demo Kit M183, DODIC M757, 372 tons		2. 16 individual 1.25 lb blocks of plasticized explosive that is easily cut using nonsparking hand tools or an automated cutting system.
3. Dynamite, Military M1 TNT, DODIC M591, 421 tons		3. Use OD or OB if the TNT is determined to be unstable due to age.
4. Canister, Mine HE F/XM 87 Volcano, DODIC K045, 216 tons 5. Sonobuoy AN/SSQ-110, DODIC 8W77, amount not provided 6. Signal Underwater Sound, DODIC SW37, 133 tons		4, 5, and 6. PD Demil currently disassembles these munitions for OB/OD demilitarization.
7. Mine, APERS, M18A1 w/firing device, DODIC K143, 169 tons		7. Commonly called “Claymore mine,” consisting of explosive in a plastic housing.

[a] Note that munitions identified by PD Demil as unstable and possibly shock sensitive are appropriate for OB/OD and are not included in this table.
[b] Quantities are provided in gross tons, not NEW, [c] Numbered notes correspond to the numbered items in the first column.

MUNITIONS NOT SUITABLE FOR DEMILITARIZATION USING EITHER OB/OD OR ALTERNATIVE TECHNOLOGIES

PD Demil informed the committee that they are not able to demilitarize approximately 6 percent of the B5A account munitions using either OB/OD or alternative technologies.[8] This 6 percent is quantified as 22,867 tons in a separate presentation to the committee.[9] If correct, these munitions would constitute an important "capability gap," as there would not be a current demilitarization method for these munitions and they would need to be stored indefinitely. Please note that this 6 percent is part of the total B5A account and not the "top 400 munitions" that are the focus of this report.

The committee's analysis shows that this category is possibly smaller than the 6 percent cited by PD Demil. The reason for this difference lies in varying definitions of the term "capability gap." In one presentation to the committee, "capability gap" is defined as: "Diminishing returns for item specific methods," which the committee interprets to mean that an available alternative technology exists but has been determined to be inadequate or inefficient.[10] Examples of munitions in this category provided to the committee are: improved conventional munitions, munitions with depleted uranium (DU), smoke-producing munitions, and obsolete rocket and missile motors.

However, the committee notes that:

- Improved conventional munitions are already being demilitarized by a contractor using alternative disposal methods;
- DU projectiles are being removed from the DU munitions and the DU and other components are being demilitarized using alternative technologies;
- There are alternative technology capabilities to dispose of smoke-producing munitions, including white phosphorus, and a commercial contract for alternative technology demilitarization of hexachloroethane (HC) riot control agent; and
- The new ARMD facility at LEMC, which appears to be able to demilitarize all ammonium perchlorate rocket and missile motors using an alternative technology.

For these reasons, the committee believes it is possible that the 6 percent estimate of munitions in this category may be high.

A revised definition of "capability gap" was subsequently provided to the committee: "[PD Demil] has not yet demonstrated an approved method for demilitarizing that item at either a government or a contractor site."[11] This presentation also provided more information on some of the specific munitions that comprise this category. However, as noted in Table 7.8, it is possible that existing alternative technologies can be used to demilitarize at least some of these munitions.

The committee's analysis indicates that the actual capability gap for munitions demilitarization is possibly less than the cited 6 percent of the B5A account munitions. However, the committee believes that these true "capability gaps," defined earlier in this chapter to be "the inability to perform a demilitarization task on the 'top 400' munitions in the B5A account due to a lack of adequate equipment or processes," are appropriately the focus of the PD Demil research, development, test, and evaluation program.

TABLE 7.8 Sample of Munitions Identified as "Capability Gaps" and Possible Existing Alternative Treatments

Munition Identified As Capability Gap	Possible Existing Alternate Treatment Approaches
1,000 lb general-purpose bomb, DODIC E506	Size reduction followed by demilitarization in CB
CS riot control agent (5 DODICs)	Commercial treatment process such as that contracted for HC smoke[a]
AP rocket motors (7 DODICs)	LEMC ARMD facility currently undergoing permit testing

[a] The source for this item is J. McFassel, product director for Demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

REFERENCE

Keller, J. 2015. Army launches biggest project in past 20 years to dispose of surplus and obsolete munitions. https://www.militaryaerospace.com/articles/2015/06/munitions-demilitarization-contract.html.

[8] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

[9] J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee, August 22, 2017.

[10] J. McFassel, product director for demilitarization, PEO AMMO, "Demilitarization Overview for National Academy of Sciences," presentation to the committee, August 22, 2017.

[11] J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee, October 23, 2017.

8

Comparative Assessment of Demilitarization Technologies

OVERVIEW

Chapter 4 reviews alternative demilitarization technologies, and Chapter 7 identifies a number of examples of alternative technologies that could be used in lieu of open burning (OB) or open detonation (OD). This chapter compares those alternative technologies to OB or OD in terms of each of the evaluation criteria defined in Chapter 5. Contained burning (CB) and contained detonation (CD) comprise most of the alternative technologies evaluated, but other technologies are included if they can be used in lieu of OB/OD. The demilitarization technologies that the committee concluded could be used in lieu of OB or OD are summarized below in Table 8.1, and the committee's technology comparison ratings are summarized in Tables 8.2 and 8.3. In the comparison tables, a "0" rating is applied to OB and OD for each of the nine criteria and then each alternative is evaluated against that baseline. A "–" indicates that, in the committee's judgment, a particular technology performs less effectively than either OB or OD in terms of that specific criterion. A "+" indicates that, in the committee's judgment, a particular technology performs better or more effectively than either OB or OD in terms of that specific criterion. A "0" indicates that, in the committee's opinion, a particular technology is substantially the same as OB or OD in terms of that specific criterion. In the case of one criterion, throughput capacity, the rating is dependent on the munition(s) being treated; in that case, the rating provided is "D," indicating that whether an alternative technology would have a better or worse throughput than OB or OD depends on the munition being treated.

Rankings of + and – do not indicate how *much* more or less effectively technologies perform relative to OB and OD, only that, in the committee's judgment, they are qualitatively better or worse, or more or less effective, than the baseline. A rigorous, quantitative evaluation of each technology against OB and OD would require a great deal of information that was not available to the committee.

ALTERNATIVE TECHNOLOGIES EVALUATED

As discussed in Chapter 7, there are several alternative CB technologies that can be used in lieu of OB and several alternative CD technologies that can be used in lieu of OD. It should be noted, however that

- Some alternative technologies can be used to replace both OB and OD. For example, rotary kiln incinerators (RKIs) and the Static Detonation Chamber (SDC) are both classified by the committee as CB systems, but they both also have the potential to replace either OD or OB, depending on which munitions are being demilitarized.
- Some alternative CB and CD technologies can be used to process an entire munition of one type, but would need one or more preprocessing steps for other munition types, depending on munition physical size, net explosive weight (NEW) content, internal components (e.g., submunitions), and other factors.

The following section describes the organic and industrial alternative technologies evaluated by the committee that can be used for demilitarization instead of OB and OD.

Technologies That May Be Used to Replace OB

CB Chambers

As shown in Chapter 7 and based on its research and analysis, the committee believes that most of the energetics and other material currently being treated by OB at the stockpile sites can be demilitarized in CB chambers. Applicable alternative (contained disposal) technologies include the following:

- CB chambers with pollution abatement systems (PASs) similar in concept to the one used at Camp

TABLE 8.1 Summary of CB and CD Demilitarization Technologies That Can Be Used to Replace OB or OD

Technology	Description
Energetic materials CB	Energetics incineration with PAS (e.g., a batch system similar to that used at Camp Minden)
Rocket and missile motor CB	Rocket and missile motor firing in contained chamber with PAS
Bulk Energetics Disposal System (BEDS) CB	Slurried bulk energetics incineration in rotary kiln incinerator with PAS
iSCWO	Slurried energetics oxidation/mineralization
MuniRem	Cleaning of contaminated surfaces using sulfur reduction chemistry
Alkaline hydrolysis	Energetics hydrolysis in sodium hydroxide
SDC	Energetics deflagration/detonation in externally heated confined chamber with PAS (no donor charge)
RKIs	Incineration in contained chambers with PAS
Flashing furnaces	Burning of energetics on metal surfaces with PAS
CDC	Contained detonation using donor charge
DAVINCH	Contained detonation using donor charge
Decineration process	Destruction of small munitions in externally heated commercial process with PAS

TABLE 8.2 Comparison of OB and Technology Alternatives to OB (Does Not Include Treatment Trains)[a]

Technology	Throughput Capacity	Environmental and Public Health Impacts[c]	Personnel Safety[d]	Cost[e]	Maturity and Permitability[f]	Monitorability[g]	Public Confidence in Technology[h]
OB	0	0	0	0	0	0	0
Energetic materials CB	D[b]	+	0	-	0	+	+
Rocket and missile motor CB	D	+	0	-	0	+	+
Bulk Energetics Disposal System CB	D	+	0	-	0	+	+
iSCWO	D	+	0	-	-	+	+
MuniRem	D	+	0	-	-	+	+
Alkaline hydrolysis	D	+	0	-	-	+	+
SDC	D	+	0	-	0	+	+
Rotary kiln incinerators	D	+	0	-	0	+	+[i]
Flashing furnaces	D	+	0	-	0	+	+

[a] OB serves as the baseline for comparison with a "0" rating for each criterion, "–" indicates that the alternative technology performs less effectively than OB, "+" indicates that the technology performs better than OB, and "0" indicates the technology is about the same as OB in terms of each criterion.
[b] D, depends on treatment technology capability, munitions characteristics, and permit restrictions.
[c] All alternative technologies are enclosed and have lower emissions than OB, so perform better in terms of environmental and public health impacts.
[d] All alternative technologies are assumed to have been reviewed by the Department of Defense Explosives Safety Board (DDESB), so are equivalent in terms of safety.
[e] Alternative technologies are considered more expensive than the relatively low-tech OB, based solely on the need to site, design, install, and operate new facilities.
[f] Alternative technologies that have been permitted are assumed to be mature and as easy to permit as OB, but if a technology is not mature and has not yet been permitted, it will be more difficult to permit than OB.
[g] Unlike OB, alternative technologies can be engineered with a PAS, so are more easily monitorable.
[h] Public confidence is a function of technologies' characteristics and potential risks, as well as people's assessments of their management and related decision-making processes, which are site-specific and difficult to predict, but the committee believes that, in general, alternative technologies may be more acceptable to the public than OB.
[i] Despite the long history of public opposition to incineration, that opposition may no longer apply in specific instances to incinerators with newer state-of-the-art pollution abatement technologies.

TABLE 8.3 Comparison of OD and Technology Alternatives to OD (Does Not Include Treatment Trains)[a]

Technology	Throughput Capacity	Environmental and Public Health Impacts[c]	Personnel Safety[d]	Cost[e]	Maturity and Permitability[f]	Monitorability[g]	Public Confidence in Technology[h]
OD	0	0	0	0	0	0	0
CDC	D[b]	+	0	-	0	+	+
DAVINCH	D	+	0	-	0	+	+
SDC	D	+	0	-	0	+	+
Rotary kiln incinerators	D	+	0	-	0	+	+[i]
Decineration furnace	D	+	0	-	0	+	+

[a] OD serves as the baseline for comparison with a "0" rating for each criterion, "–" indicates that the alternative technology performs less effectively than OD, "+" indicates that the technology performs better than OD, and "0" indicates the technology is about the same as OD in terms of each criterion.
[b] D, depends on treatment technology capability, munitions characteristics, and permit restrictions.
[c] All alternative technologies are enclosed and have lower emissions than OD, so perform better in terms of environmental and public health impacts.
[d] All alternative technologies are assumed to have been reviewed by the DDESB, so are equivalent in terms of safety.
[e] Alternative technologies are considered more expensive than the relatively low-tech OD, based solely on the need to site, design, install, and operate new facilities.
[f] Alternative technologies that have been permitted are assumed to be mature and as easy to permit as OD, but if a technology is not mature and has not yet been permitted, it will be more difficult to permit than OD.
[g] Unlike OD, alternative technologies can be engineered with a PAS, so are more easily monitorable.
[h] Public confidence is a function of technologies' characteristics and potential risks, as well as people's assessments of their management and related decision-making processes, which are site-specific and difficult to predict, but the committee believes that, in general, alternative technologies may be more acceptable to the public than OD.
[i] Despite the long history of public opposition to incineration, that opposition may no longer apply in specific instances to incinerators with newer state-of-the-art pollution abatement technologies.

Minden, Louisiana, for destruction of energetics, but at a smaller scale;

- Rocket and missile motor CB systems, such as the Ammonium Perchlorate Rocket Motor Destruction (ARMD) facility at Letterkenny Munitions Center (LEMC) used for ammonium perchlorate-based propellants, and similar chambers that have been used elsewhere; and
- Energetics disposal systems involving water slurry feed of bulk propellants into a rotary kiln incinerator for contained burn.

Other Energetics Destruction Technologies

The following technologies are not CB technologies in that they do not thermally treat materials with a burner, but are capable of chemically treating slurried energetics and contaminated surfaces. All have limited throughputs for most munition types, however. These are

- industrial supercritical water oxidation (iSCWO) for slurried energetics,
- MuniRem for energetics, and
- Alkaline hydrolysis.

Technologies That May Be Used to Replace OD

Demilitarization technologies that can be used instead of OD consist of CD chambers where an initiating (donor) charge is used to detonate explosive materials in the munitions. Their throughput capacities and NEW containment limitations vary with the munition and the size of the CD chamber. For example, the Controlled Detonation Chamber (CDC) models T-60 and D-100 are approved for NEW capacities of 40 lb and 49.3 lb, respectively. The Detonation of Ammunition in a Vacuum Integrated Chamber (DAVINCH) model DV-60 is approved for a NEW capacity of 132 lb, and the smaller DAVINCH lite is approved for 53 lb NEW. For these technologies, the NEW rating includes that of the donor charge, which can be a significant fraction of the total NEW per cycle, thus limiting the munition NEW to be destroyed in the chamber.

CB Technologies That May Be Used to Replace Both OB and OD

Several technologies have the potential to be used as replacements for both OB and OD, depending on the munition (described as dual-use technologies in Chapter 4). These are

- The SDC;
- Various RKIs such as the ammunition peculiar equipment (APE) 1236, the Explosive Waste Incinerator, and the General Dynamics Rotary Kiln Incinerator; and
- The Decineration process.

All of these have explosion containment capabilities that depend on the feed rate (number of feed cycles per hour) and the NEW of the munitions or munition components being processed per cycle. NEW capacities for these technologies range from 300 to 600 lb per hour.

Industrial Capabilities as Alternatives to OB/OD

Demilitarization of conventional munitions is also carried out by private sector Army contractors that are not allowed to use OB or OD as demilitarization methods. Those companies demilitarize munitions in processing lines, where they perform automated disassembly of complex munitions, remove shaped charges and other internal components, thermally destroy energetics, clean the munition bodies, and use a PAS to treat offgases and other process effluents.

TECHNOLOGY COMPARISONS

CB and CD treatment alternatives that the committee determined could be used to replace OB and OD are summarized in Table 8.1 and evaluated qualitatively in Tables 8.2 and 8.3, respectively, using OB and OD as the baselines for comparison and the evaluation criteria described in Chapter 5. The committee did not evaluate munitions preparation technologies separately (e.g., technologies used for size reduction such as water jets, cryofracture, and band saws) because those technologies cannot replace OB and OD. They are also completely mature and currently in use for munitions demilitarization. Appropriate munitions preparation technologies can be evaluated based on their specific demilitarization requirements.

Explanation of OB/OD and Comparable Technologies Ratings

Throughput Capacity

Throughput capacity refers to the nominal rate at which munitions can be processed. The committee rated throughput capacity D (dependent) in all cases because throughput is dependent on many factors, some of which may offset each other. Those factors include the capability of the treatment technology, the characteristics of the munitions or munition components being treated, and permit requirements, as follows:

- Treatment technology capabilities vary with capacity, quantity of material fed per cycle, number of feed cycles per time period, thermal capabilities of the technology, ability of reactions to go to completion (for chemical treatment), effectiveness of PASs, physical size of munitions or components fed per cycle, and the explosive containment capacity of the technology, whether expressed in NEW allowed per cycle or per hour.
- Munition characteristics vary according to size, shape, ability to be disassembled, energetic deflagration potential, and the need for pre- and post-processing steps. Physically small munitions, for example, with NEWs that fall within the capabilities of the technology, may be processed with minimal or no pretreatment. Munitions containing large explosive charges, shaped charges, propellant, and perhaps submunitions require one or more preprocessing steps to separate components and reduce NEW content.
- Permit requirements generally constrain the frequency of OB and OD operations according to meteorological conditions, limiting the rate at which munitions may be destroyed. Permit conditions can also limit processing rates for alternative technologies with requirements such as NEW limitations and operating restrictions (e.g., cool-down).

Although in general alternative technologies may be expected to have lower throughput rates than OB or OD, the ability of a CB or CD chamber to operate on a more predictable schedule, unconstrained by meteorological conditions, could result in a higher overall throughput rate over the life cycle of the unit for a specific feed or technology when compared to OB or OD operations.

Environmental and Public Health Impacts

This criterion refers to the potential environmental and public health impacts of emissions and discharges to all environmental media (air, water, soil) during operations, to discharges of any secondary waste streams generated during processing, and to the ability to prevent or manage them during or after operations. It also refers to community impacts of vibration, noise and shock, and odor. Regulators consider permitted OB/OD operations to be protective of public health and the environment.

During OB, thick plumes of smoke and particulates are often visible, continuing for some time after the event. OD typically results in large amounts of debris and potentially contaminated soil spread over a large area. In the case of OD, a covered pit may limit the range of fragments. The control of emissions is dependent upon a number of factors, however, each of which is controlled to some extent under the permit conditions for OD events at a particular facility (DoA, 1982). As evidenced by the demilitarization program's practice, Department of Defense (DoD) policy requires installations to have reuse, recovery, and recycling programs that properly and cost effectively manage materials in accordance with the DoD pollution prevention hierarchy (DoD, 2016).

Because all the alternative technologies are enclosed and almost always involve some form of PAS, community impacts and emissions to the environment are typically smaller and pose less risk than OB/OD.

Personnel Safety

The Office of the Product Director for Demilitarization has stressed, and the committee concurs, that preventing worker injury is paramount in any demilitarization operation. However, no demilitarization process is without risk. OB and OD require that personnel handle munitions and, for OD, donor charges, thereby exposing themselves to explosive hazards. In general, more munitions handling and more personnel contact is required when demilitarizing munitions via an alternative process, depending on the extent to which automation has been implemented for activities such as disassembly; CB and CD technologies typically involve more handling of munitions. A notable exception to this generality is the SDC, which involves less munitions handling than OB/OD for munitions that meet the NEW requirement for direct insertion into the SDC.

For most munitions and processes, personnel safety issues are addressed through appropriate engineering (e.g., prevention through design) and through the development of, and strict compliance with, technology-specific standard operating procedures, as currently required by the Office of the Product Director for Demilitarization and the DDESB. However, OB, OD, and all the alternatives involve some degree of risk to personnel. The committee believes that the currently required DDESB safety approvals for both OB/OD and CB/CD and their associated demilitarization processes are adequate to minimize explosive accidents and injuries. For this reason, the committee has rated all technologies that it evaluated as “0”—that is, unlikely to differ substantially from OB/OD.

Additionally, some shock sensitive or unstable munitions may not be safe to handle or transport for treatment by alternative technologies; thus, the capability for OB/OD will always be needed.

Cost

The Army has estimated that the operational cost of OB/OD is $750/ton, which is lower than the operational cost of CB/CD, estimated by the Army as $2,000 to $20,000/ton.[1] The committee estimated that the operational cost of the Camp Minden emergency propellant CB was about $3,500/ton,[2] which would likely be reduced under nonemergency conditions. In that case, the cost of propellant CB could be cost-competitive with OB.

Actual costs of demilitarization are not limited to operational costs, however, and include capital (startup), operational, environmental monitoring, and closure costs. DoD guidance specifically requires consideration of life cycle costs (LCCs), not just operational costs. According to DoD guidance, life cycle cost is defined as “the cost to the government of a program over its full life, including costs for research and development; testing; production; facilities; operations; maintenance; personnel; environmental compliance; and disposal.”[3] The committee was unable to obtain sufficiently detailed information to address and compare the LCC of OB/OD or the alternative technologies. Estimates of capital, monitoring, and closure costs for the alternative technologies or the existing OB/OD units at the seven depots were also largely unavailable. The committee believes that the capital (startup) costs of the alternatives would likely be considerably higher than those for OB/OD, while the closure costs associated with the alternative technologies would likely be considerably lower than those for OB/OD. Adequate data to perform a quantitative analysis were not provided, however.

The committee did obtain some information about the LCC of the Camp Minden operation based on the contractor’s project proposal (EPA, 2015). In that case, the cost of mobilization and site preparation, destruction of 15,700,000 lb of M6 propellant and 320,000 lb of clean burning igniter, basic pollution abatement and environmental monitoring, and site restoration produced an estimate for demilitarization of about $3,500/ton.

The committee also concluded that if a demilitarization facility, whether OB/OD or an alternative, is operated for decades, the cost of closure and cleanup as a function of dollars per ton demilitarized would likely decrease to the point where it becomes less significant compared to total cost.

Maturity and Permitability

Maturity is how far a technology has developed to ensure reliable operation. Permitability is the ability to obtain an operating permit. The two are very much related. If a technology is not mature, it is unlikely to have a Resource Conservation and Recovery Act (RCRA) operating permit. Among other things, a series of tests, calculations, assessments, and evaluations are needed to obtain a permit. The more locations

[1] J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO, “Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation,” presentation to the committee on August 22, 2017.

[2] Based on cost estimate found in contractor’s proposal for removal and disposal operations involving 15,700,000 lb of M6 propellant at $0.90/lb (EPA, 2015).

[3] Life cycle cost (LCC) definition, https://www.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=e8a6d81f-3798-4cd3-ae18-d1abafaacf9f.

at which a technology has been permitted, the more likely regulators will be familiar with the technology. In that case, the permit requirements needed to ensure a technology is implemented in a manner that protects human health and the environment are fairly well established. Of course, both OB and OD are mature technologies, both being used for decades and both having been permitted at a number of locations. Those alternative technologies currently permitted at various locations are also considered mature.

Monitorability

Monitorability is the degree to which effluents can be monitored during and after demilitarization activities. Monitoring characterizes environmental releases, personnel exposures, and public exposures, should they occur, thus providing information about how well a technology is meeting permit requirements. The committee concluded that each of the alternative technologies evaluated would be more easily monitorable than OB/OD. Although permits for OB/OD operations include monitoring requirements, those pertain to the monitoring of environmental media following operations. Each of the alternative technologies that could be used to replace OB or OD can be engineered with a PAS that includes monitoring of the process effluents to ensure that emissions do not exceed regulatory limits. Although a hold-test-release design could confirm that emissions standards are being met, hold-test-release was developed for demilitarization of chemical weapons due to their high acute toxicity; the committee believes that this capability is not needed or appropriate for conventional munitions.

Public Confidence

Public confidence in both the alternative technologies themselves and how their operations are likely to be managed by the Army can impact implementation of alternative technologies at particular sites. One impetus for this committee's report was public interest groups' concerns about potential environmental and public health impacts associated with OB and OD. By reducing environmental impacts (e.g., through using contained systems), reducing potential public health risks (e.g., through lower emissions), and implementing some level of monitoring capability, alternative technologies can better address public concerns. Addressing public concerns in a meaningful manner can promote public confidence, and thus support acceptance and legitimacy for new demilitarization technologies. However, a strong caveat is required. Public confidence is a function of technologies' characteristics and potential risks, as well as people's assessments of the technologies' management and related decision-making processes, which are difficult to predict (see Chapters 9 and Appendix D). Public confidence is site specific and reflects the public's understanding and beliefs about the history of the technologies' management at particular sites. In general, however, the committee believes that alternative demilitarization technologies will be more acceptable than OB/OD.

In the case of incineration, there has been a long history of public opposition. Concluding that there will necessarily be community opposition in the future to incineration technologies that use state-of-the-art PAS controls is inappropriate, however. The assumption that there will be opposition is based on historical experiences that may no longer apply.

Finding 8-1. Each of the alternative technologies that the committee evaluated as potential replacements for OB and OD would have lower emissions and less of an environmental and public health impact, would be monitorable, and would likely be more acceptable to the public.

Finding 8-2. Throughput capacity for OB and OD and alternative technologies is dependent on many factors, some of which may offset each other. These factors include the capability of the treatment technology, the characteristics of the munition or munition component being treated, and permit restrictions.

Finding 8-3. Most of the alternative technologies that could replace OB and OD are mature and many have already been permitted.

Finding 8-4. The alternative technologies that could replace OB and OD could pose either more or less risk to personnel depending on the munition and on the extent to which munitions handling is required. The safety approvals currently required by the DDESB for both OB/OD and CB/CD and their associated demilitarization processes are adequate to minimize explosive accidents and injuries.

Finding 8-5. Hold-test-release capability is neither necessary nor appropriate for technologies treating conventional munitions and associated wastes because of the difference in acute toxicity between chemical warfare agents and the components of conventional munitions.

Finding 8-6. The committee requested but was unable to obtain sufficient data to draw general conclusions regarding the relative LCC of OB and OD and the alternative technologies, although the capital (startup) costs of the alternatives will likely be higher while the costs of environmental monitoring and closure will likely be lower. Operating costs of the alternatives appear to vary widely and in some cases may be competitive with OB/OD.

REFERENCES

DoA (U.S. Department of the Army). 1982. TM 9-1300-277. Technical Manual General Instruction for Demilitarization/Disposal of Conventional Munitions. Section 2-2(7). https://www.epa.gov/sites/production/files/2015-03/documents/9545926.pdf.

DoD (U.S. Department of Defense). 2016. DoD Instruction 4715.23. Integrated Recycling and Solid Waste Management. http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471523_dodi_2016.pdf.

EPA (U.S. Environmental Protection Agency). 2015. Preliminary List of Potential Technologies for the Destruction of M6 at Camp Minden, draft 2/22/15. Environmental Protection Agency: Washington, D.C.

9

Barriers and Other Considerations

Section 1421 of the National Defense Authorization Act (NDAA) for Fiscal Year 2017[1] and this committee's statement of task require the identification and evaluation of "any barriers to full-scale deployment of alternatives to open burning, open detonation, or non-closed loop incineration/combustion and recommendations to overcome such barriers." In the context of this report, the committee defines the following terms:

- *A barrier* as something that must be overcome in order for alternative technologies to be applied to munitions within the demilitarization stockpile that are currently being treated via open burning (OB) or open detonation (OD); and
- *Full-scale deployment* of alternative technologies as maximizing the use of alternative technologies for all munitions in the stockpile that are currently being treated via OB/OD, to the extent possible, using (1) existing facilities; (2) designing, installing, permitting, systemizing, and deploying technologies at one or more Army demilitarization depots; or (3) initiating contracts with commercial facilities.

The Office of the Product Director for Demilitarization (PD Demil) provided information to the committee concerning the reason OB/OD was selected for the munitions on the list of the top 400 Department of Defense Identification Codes (DODICs) in the stockpile. The most common reasons given were safety—for example, the requirement to disassemble certain munitions before using alternative technologies may affect personnel safety and a lack of organic alternative technologies on-site at the depot where the munition was stored.[2] Representatives of PD Demil also expressed concerns that the lower throughput attributable to some alternative technologies could impact the mission readiness of the DoD, although they also stated that currently existing alternative technology units are not being used to their maximum capacity and that PD Demil could improve and maximize the throughput of existing alternative technology units. PD Demil pointed out that it has used research, development, test, and evaluation funding to address efficiency of alternative technologies, including (1) expanding the APE 1236 for dual feed to get more throughput rather than limiting campaigns to single munition types and (2) implementing cryofracture preprocessing to support the use of other alternative technologies, such as contained burn chambers.[3]

The committee agrees that human health and personnel safety are the paramount reason that all demilitarization technologies must be evaluated and chosen carefully (see Chapters 2 and 6). However, the committee believes that if alternative technologies are available at other stockpile depots[4] or through commercial contracts, it would be appropriate for PD Demil to consider all of these resources when deciding what technology to use, taking into consideration all pertinent criteria such as transportation cost, risk and public acceptance, and that the lack of an organic, on-site technology should not be the Army's sole reason for continued use of OB/OD. The committee also believes that the required disassembly of munitions is not a significant barrier to using alternative technologies while ensuring minimal exposure of personnel to explosive safety risks (see Chapters 4, 7, and 8). The committee discussions in the previous chapters indicate that there are no significant technical, safety, or regulatory barriers to designing, installing, permitting, systemizing, and

[1] Public Law 114-328, 130 Stat. 2571, December 23, 2016, Section 1421.

[2] Copy of Information Request on OBOD Munitions.xlsx, October 2017.

[3] Telephone conference call with PD Demil, June 6, 2018.

[4] The Army indicated that between 7 and 15 percent of the current stockpile being treated via OB/OD could be treated by alternative technologies at another organic installation. J. McFassel, product director for demilitarization, PEO AMMO, and O. Hrycak, chief engineer, Office of PD Demilitarization, PEO AMMO, "Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation," presentation to the committee, August 22, 2017.

deploying alternative technologies for demilitarization of the vast majority of the conventional waste munitions in the Army stockpile that cannot be overcome. Only a relatively small quantity of unstable munitions that present safety concerns absolutely require use of OB/OD (see Chapter 7).

The committee believes that there is only one barrier to the full-scale deployment of alternative technologies in lieu of OB/OD—namely, funding. The committee, in addition, identifies two considerations that are not barriers, but could significantly impact the effective implementation of the Army's strategy to transition away from OB/OD: (1) PD Demil's lack of a detailed implementation plan to institutionalize the 2018 Demilitarization Strategic Plan goal to increase the use of contained disposal technologies (CDTs) and reclamation, recycling, and reuse (R3); and (2) the potential for public opposition to the implementation of alternative technologies at the individual stockpile depots.

Finding 9-1. There are no significant technical, safety, or regulatory barriers to the full-scale deployment of alternative technologies for the demilitarization of the vast majority of the conventional waste munitions, bulk energetics, and associated wastes.

FUNDING BARRIER

PD Demil Funding

Funding is a significant factor in PD Demil decisions regarding selection and use of demilitarization technologies. As stated in Chapter 2, overall funding for PD Demil increased from $134 million in FY2008 to about $198 million in FY2018; an increase of about 4 percent per year (Hrycak and Crank, 2015).[5] However, the NDAA for FY2019, in reconciliation as this report was completed, shows that the Army requested and was granted only $158 million for conventional munitions demilitarization; a decrease of about 37 percent from the FY2018 appropriation of $250,826,000. These appropriations include demilitarization activities at both organic Army facilities and commercial contractors. PD Demil stated to the committee that the primary limitation on the quantity of munitions demilitarized is not technological capability or capacity, but budget.[6] In 2015, the Government Accountability Office (GAO) reported that the Army, as the Single Manager for Conventional Ammunition (SMCA), stated that the Department of Defense (DoD) demilitarization budget request frequently does not match actual funding needs because the request is based upon the estimated disposal costs required to reduce the existing conventional munitions demilitarization stockpile as well as the costs of disposing of munitions that the services forecast they will submit for disposal in the future (GAO, 2015). However, the forecast information from the services is often inaccurate, although the forecasts have been improving (see Chapter 2). GAO stated that the SMCA "addresses the funding challenge each year by developing an annual demilitarization plan to dispose of as much of the [conventional ammunition demilitarization] stockpile as it can based on the amount of funding they receive." As reported by GAO, Army officials stated that uncertainties in the amount of funding has caused them to be reluctant to initiate projects that increase demilitarization capacity or efficiency, since these capabilities may not be utilized in the future due to funding shortfalls. Furthermore, Army officials stated to GAO that they lack research, development, test, and evaluation funding to develop demilitarization processes for the disposal of some materiel in the stockpile that cannot be demilitarized using "current processes" (GAO, 2015). A December 2013 Army Audit Agency report by the Army Deputy Chief of Staff for Logistics (G-4) stated that the conventional munitions demilitarization program is considered a lower priority by the Army when compared to other needs (GAO, 2015).

Cost Estimates

Army and DoD guidance requires performance of full life cycle cost (LCC) analysis (often called Total Ownership Cost for defense systems).[7] Such a LCC analysis is necessary to make a completely informed decision on whether to implement alternative technologies in lieu of OB/OD. The LCC for each permitted unit need to include the cost of clean closure required under the appropriate regulations (see Chapters 6 and 8). Conceptually, the LCC of OB/OD should be compared to the LCC of an alternative technology (GAO, 2001; Ryan et al., 2012). If the cost of clean closure at an OB/OD site is significant, the LCC of implementing an alternative technology may not be significantly different from the LCC of an OB/OD unit. Cost estimates provided to the committee in PD Demil presentations did not include full LCC, in that they did not include clean closure costs when comparing the cost per ton of alternative technologies versus OB/OD.

The committee makes no recommendation on the priorities, funding goals, or schedules that should be adopted. The decision on funding is a policy decision to be resolved between the Army (or, more broadly, DoD) and Congress through whatever budget process is appropriate. However, the committee believes that absent a clear directive from Congress, accompanied by sufficient funding, it will not be possible for the Army to implement full-scale deployment of alternative technologies.

[5] J. McFassel, product director for demilitarization, PEO AMMO, "Clarifications on Demilitarization Policies and Procedures for National Academy of Sciences," presentation to the committee on October 23, 2017.

[6] Ibid.

[7] LCC Definition, https://www.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=e8a6d81f-3798-4cd3-ae18-d1abafaacf9f.

Finding 9-2. The implementation and use of alternative technologies is a function of how much funding is requested by the Army and how much funding is appropriated, however, both the DoD and the Army have placed a relatively low priority on funding the demilitarization program, including the implementation of additional alternative technologies to replace OB/OD, as reflected in their past budget requests.

Finding 9-3. Uncertainty in the current and future funding levels for demilitarization of conventional munitions is a barrier to the development and increased use of alternatives to OB/OD.

Finding 9-4. Absent a clear directive from Congress, accompanied by sufficient funding, it will not be possible for the Army to implement full-scale deployment of alternative technologies in lieu of OB/OD.

Recommendation 9-1. To enable the Department of Defense and Congress to decide what level of resources should be devoted to increasing the use of alternative technologies in lieu of open burning (OB) and open detonation (OD), the Office of the Product Director for Demilitarization should prepare an analysis of the full life cycle costs of demilitarization of the munitions in the stockpile using alternative technologies and OB/OD to determine the funding necessary to increase the use of alternative technologies over various periods of time and the impact of that increase on the demilitarization enterprise.

OTHER CONSIDERATIONS THAT COULD IMPACT THE FULL-SCALE DEPLOYMENT OF ALTERNATIVE TECHNOLOGIES

Lack of a Formal Plan to Transition to Alternative Technologies

In its 2007-2012 Demilitarization Strategic Plan, the SMCA stated a strategic goal to "emphasize closed disposal" (DIA, 2006). The enabling objectives/metrics for this goal were to

- Pursue and optimize cost-effective processes for CDTs, and
- Achieve a minimum level for CDTs at 80 percent of execution.

In fact, PD Demil has reduced the use of OB/OD at the seven stockpile depots substantially over the past two decades owing to a combination of the use of alternative technologies, increased reuse and recycling, and increased commercial sales or transfers (see Chapters 1 and 2).

In May 2018, the Army issued its new Demilitarization Enterprise Strategic Plan.[8] There was no strategic plan between 2012 and 2018. The committee believes the lack of a strategic plan between 2012 and 2018 may reflect the relative low priority given to demilitarization of conventional munitions, and consequently, the goal of increasing the use of alternative technologies.

The 2018 Demilitarization Enterprise Strategic Plan focuses on the following four goals:

1. Maximizing the capacity of commercial contracts (industrial base);
2. Improving the efficiency and effectiveness of demilitarization capabilities;
3. Institutionalizing design-for-demilitarization policies for all new and modified conventional munitions; and
4. Increasing the use of CDTs[9] and R3 while continuing to ensure minimal exposure of personnel to explosive safety risks.

Unlike the 2007-2012 Demilitarization Strategic Plan, the last goal in the 2018 Demilitarization Strategic Plan has no numerical goal for increasing the use of CDTs or for increasing the use of R3 in the execution of conventional munitions demilitarization.[10] There are two metrics established for Objective 4a, "Increase Use of Closed Disposal Technology."[11] The first requires reports on the "percentage of annual tonnage of munitions demilitarized using closed disposal technologies" to "document the demilitarization enterprise is not completely reliant on open burning and open detonation and is making a significant investment in closed disposal technologies which are useable, safe and environmentally compliant."[12] The second metric calculates the "total configurations in the stockpile for which closed disposal technology exists or is feasible" focused on the top 400 DODICs by weight. The metric should "show an increase from the previous year."[13]

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[8] Strategic Plan: For the Demilitarization Enterprise, draft document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 25, 2018.

[9] Although the PD Demil 2018 Demilitarization Strategic Plan uses the term "closed disposal technologies," the committee believes it is best to use the term "contained" versus "closed" for two reasons. First, because most contained burn and contained detonation systems eventually release an air stream to the environment, these systems are not truly closed. Second, the committee wants to clearly differentiate the type of treatment (open versus contained) from Resource Conservation and Recovery Act (RCRA) unit closure requirements.

[10] Although R3 is an important function for PD Demil, this committee's charge is to identify and evaluate barriers to the full-scale deployment of alternatives to OB/OD or non-closed loop (i.e., noncontained) incineration/combustion technologies.

[11] "Strategic Plan: For the Demilitarization Enterprise," draft document provided to the committee by J. McFassel, product director for demilitarization, PEO AMMO, via e-mail on May 25, 2018.

[12] Ibid.

[13] Ibid.

The metrics for the first three goals and objectives in the 2018 Demilitarization Enterprise Strategic Plan require PD Demil to determine whether the calculated metric meets established performance ratings (i.e., green, yellow, and red) to demonstrate improvement; however, the metrics for increasing the use of CDTs, and conversely the transitioning away from OB/OD, do not.[14] Therefore, other than the general, nonnumeric goal to increase the use of contained disposal and the associated general metrics calculations with no performance requirements stated in the 2018 Demilitarization Strategic Plan, it appears that neither the Army nor PD Demil has established formal internal guidance or an implementation plan for transitioning from the use of OB/OD to the use of alternative technologies.[15]

Finding 9-5. The goals and metrics in the 2018 Demilitarization Strategic Plan are focused on determining whether the program is meeting or exceeding its planned reduction in OB/OD and increase in R3, but they do not set quantitative end points or time tables.

The committee believes that there is a tendency within all organizations to resist substantive change. Switching to currently available alternative technologies for most or all munitions that are currently treated by OB/OD would involve a substantial institutional change within the Army and PD Demil. If PD Demil is to achieve its stated strategic goal to increase the use of CDTs and R3 while continuing to ensure minimal exposure of personnel to explosive safety risks, in addition to receiving the funding needed, a detailed implementation plan needs to be institutionalized within the DoD and PD Demil, taking into consideration the complex system of conventional munitions demilitarization comprised of personnel, infrastructure, technologies, as well as regulatory requirements.

Finding 9-6. PD Demil's stated goal is to increase the use of contained disposal technologies. In addition, the Environmental Protection Agency staff and state staff presentations to the committee indicated an evolving preference to move away from OB/OD. Public interest groups also support the adoption of alternative technologies.

Finding 9-7. PD Demil has no implementation plan or process for increasing the use of alternative technologies and transitioning away from OB/OD.

Recommendation 9-2. The Office of the Product Director for Demilitarization should develop a detailed implementation plan for transitioning from open burning and open detonation to alternative technologies, with appropriate performance metrics, and institutionalize it throughout the Demilitarization Enterprise.

[14] Ibid.

[15] Ibid.

Public Opposition

As discussed in Chapter 1, an impetus for this study is public opposition to OB and OD and support for seeking and using alternative technologies in lieu of OB/OD. Public interest groups presented to the committee[16, 17, 18] their concerns with OB/OD and their general support for alternative technologies that can effectively meet criteria developed by the Cease Fire! Campaign, a national coalition of more than 60 groups (see Appendix B).

Presentations and comments to the committee indicate that public interest groups do not endorse specific alternatives; rather, they want PD Demil to give serious consideration to adopting alternatives and expending efforts to test and further develop and deploy them, given site-specific concerns and considerations. Communities are likely to differ in their preferences and how they weigh the various Cease Fire! Campaign criteria. In addition, public interest groups indicated to the committee that they recognize that all of the criteria do not need to be met all the time: they are aspirational and provide a list of issues that should be explicitly considered.

Thus, public support may be context-specific, and opposition could arise about particular alternative technologies in specific communities, thereby potentially affecting full-scale deployment of alternative technologies. For example, some representatives expressed to the committee strong opposition to incineration and to intersite transportation, while another believed that thermal treatment with pollution abatement may be worth considering, especially in water-scarce areas. In addition, despite a long history of public opposition to incineration, it is incorrect to conclude that there will necessarily be community opposition in the future and in specific instances to incineration technologies utilizing state-of-the-art pollution abatement systems controls. In addition, multiple criteria have more to do with the process of selecting and implementing alternative technologies than they do with the technologies per se. Factors that can lead to opposition have been clearly articulated to the committee and are included in Appendix D.

The presentations to the committee showed that public opposition currently is centered on non-PD Demil OB/OD

[16] Lenny Siegel, executive director, Center for Public and Environmental Oversight, "Communities and Conventional Munitions Demilitarization," presentation to the committee, August 23, 2017.

[17] J. Williams, executive director, California Communities Against Toxics and F. Kelley, member, Steering Committee, Cease Fire! Campaign, Public Perspectives Panel Discussion with the National Academy of Sciences Committee on Alternatives for the Demilitarization of Conventional Munitions, October 23, 2017.

[18] D. Bledsoe, founder, Environmental Patriots of the New River Valley, "OB/OD a Living Legacy at RAAP- Radford Army Ammunition Plant/ RRAP 1941 to Present," presentation to the committee, October 23, 2017.

activities, and the committee is not aware of active local public opposition to OB/OD at the seven stockpile depots. However, it is clear that the public does not always make the distinction between different Army activities. Local and nationally organized public opposition can impact the full-scale deployment of alternative technologies through the public notice and hearing provisions during the permitting process and through legislative and regulatory changes (see Chapter 6). Indeed, inclusion of a requirement to conduct this study in the NDAA for FY2017 is a specific example of avenues of effecting change by public interest groups. The committee also notes a history of successful public advocacy forcing changes in legislative and regulatory decision making, at both local and national levels, to Army and other federal programs, particularly in the United States' chemical weapons demilitarization program.

Proactive, meaningful, and respectful engagement with the public can play an important role in building support for proposals for alternative technologies at specific facilities and communities. As discussed in Chapter 2, PD Demil does not have its own public engagement program. The Public and Congressional Affairs Office, which manages public affairs for the seven stockpile sites, is attached to, and funded by, the Joint Munitions Command (JMC). The director of the Public and Congressional Affairs Office reports to the JMC chief of staff, and the relationship to PD Demil and the demilitarization enterprise is informal. Information presented to the committee suggests that the Public and Congressional Affairs Office is not adequately staffed or funded to proactively and effectively build support for or address potential public opposition to specific alternative technologies. Last, the Public and Congressional Affairs Office is designed to focus less on public engagement or two-way communication than it is on one-way education and correcting misinformation (see Chapter 2). The experience at Camp Minden, even though not entirely collaborative or smooth (see Appendix D), demonstrates that public acceptance of alternative technologies viewed as risky may be possible when decision processes recognize the interweaving of technical and social issues, are responsive to community concerns, and promote shared learning.

Finding 9-8. There is a potential that proposals for alternative technologies to replace OB/OD at the stockpile sites could be contested by the public.

Finding 9-9. The public's acceptance of technologies that they view as being risky may be fostered if the Army adopts more effective public involvement activities. Without proactive attention by PD Demil to the ways that the perception of technology and management are intertwined, public support may be undermined, resulting in delays in full-scale deployment of alternative technologies to replace OB/OD.

Recommendation 9-3. The Office of the Product Director for Demilitarization should, in coordination with the Joint Munitions Command Public and Congressional Affairs Office, include in its implementation plans proactive public affairs activities that build on the experience of other successful programs in resolving public concerns.

REFERENCES

DIA (Defense Intelligence Agency). 2006. Strategic Plan 2007–2012 Leading the Defense Intelligence Enterprise. https://www.hsdl.org/?view&did=474568.

GAO (U.S. Government Accountability Office). 2001. Environmental Liabilities: Cleanup Costs from Certain DOD Operations Are Not Being Reported. https://www.gao.gov/assets/240/233164.pdf.

GAO. 2015. GAO-15-538. Defense Logistics, Improved Data and Information Sharing Could Aid in DOD's Management of Ammunition Categorized for Disposal. https://www.gao.gov/assets/680/671536.pdf.

Hrycak, O. and T.G. Crank. 2015. Ammunition Demilitarization Research Development Technology and Engineering Program Update. Parsippany, N.J.: 2015 Global Demilitarization Symposium. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2015/demil/Hrycak.pdf.

Ryan, E., D. Jacques, J. Colombi, C. Schubert. 2012. A Proposed Methodology to Characterize the Accuracy of Life Cycle Cost Estimates for DoD Programs. https://ac.els-cdn.com/S1877050912000749/1-s2.0-S1877050912000749-main.pdf?_tid=9f3b6d5e-74b6-4cd3-9357-828337e22d7d&acdnat=1532980883_118b1fdb514d5fe9f9b2a414c03d7b36.

Appendixes

A

Committee Activities

FIRST COMMITTEE MEETING
AUGUST 22-24, 2017
WASHINGTON, D.C.

Objectives: Conduct administrative actions, introductory discussions, bias discussion, and briefings; discuss statement of task and background with sponsor; receive briefings and engage in dialogue with briefers; review report writing process and project plan; review and flesh out initial report outline; make committee writing assignments; and set future meeting dates and determine next steps.

Demilitarization Overview, Mr. John McFassel, Product Director for Demilitarization, Program Executive Office Ammunition

Emerging Technologies Addressing Alternatives to Open Burn and Open Detonation, Mr. Orest Hrycak, Chief Engineer, Office of the Product Director for Demilitarization, Program Executive Office Ammunition

Alternatives for the Demilitarization of Conventional Munitions, Mr. Ken Shuster, Engineer, Senior Technical Expert, U.S. Environmental Protection Agency

DoD Open Burn and Open Detonation (OB/OD), Mr. J. C. King, Director for Munitions and Chemical Matters Headquarters, Department of the Army, Office of the Deputy Assistant Secretary of the Army for Environment, Safety, and Occupational Health

Communities and Conventional Munitions Demilitarization, Mr. Lenny Siegel, Executive Director, Center for Public and Environmental Oversight

Explosive Destruction System Presentation, Mr. Larry Gottschalk, Project Manager, Non-Stockpile Chemical Materiel Disposal

Anniston Static Detonation Chamber Status, Mr. Tim Garrett, Anniston Site Project Manager, Program Executive Office for Assembled Chemical Weapons Alternatives

Patented "Decineration™" Thermal Process, Mr. David Kautz, President and CEO, U.S. Demil, LLC

TELECONFERENCE WITH THE PRODUCT MANAGER FOR DEMILITARIZATION
SEPTEMBER 27, 2017

Objective: To obtain answers to committee questions.

TELECONFERENCE WITH CALIFORNIA COMMUNITIES AGAINST TOXICS AND CEASE FIRE! CAMPAIGN
OCTOBER 17, 2017

Objective: To engage with representatives and leaders of public interest groups to better understand their concerns about open burning and open detonation and their perspectives on alternative technologies.

SECOND COMMITTEE MEETING
OCTOBER 23-25, 2017
WASHINGTON, D.C.

Objectives: Conduct administrative actions and bias discussion; receive briefings and engage in dialogue with briefers; review and flesh out concept draft; make committee writing assignments; and set future meeting dates and determine next steps.

The Committee's Approach to Public Engagement, Dr. Judith Bradbury and Dr. Seth Tuler, Members, Committee on Alternatives for the Demilitarization of Conventional Munitions

Conventional Munitions and Factors Affecting Demilitarization, Mr. John McFassel, Product Director for Demilitarization, Program Executive Office Ammunition

*The EPA Position on Open Burning, Open Detonation, and Alternative Techn*ologies, Mr. Ken Shuster, Engineer, Senior Technical Expert, U.S. Environmental Protection Agency

Public Perspectives (Panel): Ms. Devawn Bledsoe, Founder, Environmental Patriots of the New River Valley; Ms. Jane Williams, Executive Director, California Communities Against Toxics; and Ms. Frances Kelley, Member, Steering Committee, Cease Fire! Campaign

Static Firing to Demilitarize Rocket and Missile Motors, Mr. Jeff Wright, G-3 Chief Engineer, U.S. Army Aviation and Missile Life Cycle Management Command

Chemical Neutralization Applications in Demilitarization of Conventional Munitions, Dr. Valentine Nzengung, MuniRem Environmental

El Dorado Engineering's Technologies for the Demilitarization of Conventional Munitions, Mr. Robert Hayes, President, El Dorado Engineering

SITE VISIT TO THE LETTERKENNY MUNITIONS CENTER

OCTOBER 26, 2017

LETTERKENNY ARMY DEPOT, PENNSYLVANIA

Objectives: Visit the Letterkenny Munitions Center, located on the Letterkenny Army Depot; visit a demilitarization operation that demilitarizes rockets and missiles using recovery and recycling; observe an open detonation event and the static firing of missile motors; visit the Ammonium Perchlorate Rocket Motor Destruction facility. No presentations.

THIRD COMMITTEE MEETING

DECEMBER 11-13, 2017

WASHINGTON, D.C.

Objectives: Receive briefings and engage in dialogue with briefers; work on the report draft; make committee writing assignments; and set future meeting dates and determine next steps.

Munitions Not Able to Be Processed by Alternative Technologies at Depots and Why, Mr. John McFassel, Product Director for Demilitarization, Program Executive Office Ammunition

Munitions Items Disposition Action System (MIDAS), Mr. John McFassel, Product Director for Demilitarization, Program Executive Office Ammunition

Department of Defense Explosives Safety Board (DDESB), Mr. Thierry L. Chiapello, Executive Director, DDESB

Public Engagement by the Joint Munitions Command (JMC), Ms. Justine Barati, Chief of Public Affairs, JMC

General Atomics' Approaches to Size Reduction and Munition Disassembly, Mr. John Follin, Director, Strategic Development for iSCWO and Demilitarization Technologies, General Atomics

Pennsylvania Regulatory Perspectives, Ms. Linda Houseal, Pennsylvania Department of Environmental Protection (via web meeting)

Alabama Regulatory Perspectives, Mr. Stephen Cobb, Chief, Land Division, Alabama Department of Environmental Management

TELECONFERENCE WITH JOINT MUNITIONS COMMAND PUBLIC AFFAIRS OFFICE

JANUARY 26, 2018

Objective: To better understand how Joint Munitions Command conducts its public affairs activities in relation to the demilitarization of conventional munitions, especially through open burning and open detonation.

TELECONFERENCE WITH CALIFORNIA COMMUNITIES AGAINST TOXICS AND CEASE FIRE! CAMPAIGN

JANUARY 31, 2018

Objective: To engage with representatives and leaders of public interest groups to better understand their concerns about open burning and open detonation and their perspectives on alternative technologies.

TELECONFERENCE WITH THE PRODUCT MANAGER FOR DEMILITARIZATION

JANUARY 31, 2018

Objective: To obtain answers to committee questions.

TELECONFERENCE WITH ENVIRONMENTAL PATRIOTS OF THE NEW RIVER VALLEY

FEBRUARY 1, 2018

Objective: To engage with representatives and leaders of public interest groups to better understand their concerns about open burning and open detonation and their perspectives on alternative technologies.

FOURTH COMMITTEE MEETING

MARCH 19-21, 2018

WASHINGTON, D.C.

Objectives: Work on the report draft; identify findings and recommendations; identify points of contention; map out path to concurrence at the next meeting; and make committee writing assignments.

TELECONFERENCE WITH STRATEGIC ENVIRONMENTAL RESEARCH AND DEVELOPMENT PROGRAM

APRIL 16, 2018

Objective: To obtain environmental information about emissions from open burning and open detonation, and learn more about characterizations of these emissions.

TELECONFERENCE WITH JOINT MUNITIONS COMMAND PUBLIC AFFAIRS OFFICE

APRIL 19, 2018

Objective: To better understand how Joint Munitions Command conducts its public affairs activities in relation to the demilitarization of conventional munitions, especially through open burning and open detonation.

TELECONFERENCE WITH THE PRODUCT MANAGER FOR DEMILITARIZATION

MAY 9, 2018

Objective: To obtain answers to committee questions.

TELECONFERENCE WITH THE PRODUCT MANAGER FOR DEMILITARIZATION

JUNE 5, 2018

Objective: To obtain answers to some final questions.

FIFTH COMMITTEE MEETING

JUNE 11-13, 2018

WASHINGTON, D.C.

Objectives: Resolve overarching issues; agree on report main messages; finalize findings and recommendations; review report and resolve all remaining points of contention; achieve concurrence.

B

CEASE FIRE! Campaign Technology Criteria

1. Overall protection of human health and the environment:[1]
   a. Treatment method is fully protective of human and ecological health and prevents toxic emissions.
   b. Treatment method offers maximum protection to workers.
   c. Treatment method is sensitive to the elevated levels of pollution that already exist in the area (such as current [nitrogen oxides], and ground-level ozone levels).
   d. Treatment method does not cause or contribute to soil, air, or water pollution.
   e. Any residue from treatment is fully and accurately characterized and safely disposed of.
   f. Treatment method offers maximum safety controls to prevent any and all releases.
   g. Treatment method prevents the potential for catastrophic release.
   h. Treatment method has aggressive process safety management protocols.
   i. Treatment method is fully protective of human health and the environment even when full characterization of wastes is not possible.
   j. Treatment method is fully protective of marine and aquatic receptors and ecosystems, including fisheries.

2. Monitorability:
   a. Treatment method can be monitored effectively, both at the site and in the surrounding community, and tested to assure protective levels of contamination before any possible release (sometimes referred to as hold, test, and release).
   b. All effluents from the treatment system should be monitorable, including solids, gases, and liquids.

3. Long-term effectiveness and permanence:
   a. Treatment method is a complete solution, minimizing the need for additional treatment, long-term storage or disposal in the future.
   b. Treatment method does not require long-term maintenance, storage and monitoring and effectively eliminates any long-term liability to this or future generations.
   c. Treatment method allows the property to be returned to unrestricted and productive use.
   d. Treatment method is superior when fiscal considerations are fully inclusive of ecological, environmental, health, remedial, investigative, site closure, residual contamination burden, and other life-cycle costs.

4. Reduction of toxicity, mobility, or volume through treatment:
   a. Treatment method/remedy does not create a more toxic byproduct (such as dioxins and products of incomplete combustion) that does not already have an authorized treatment plan.
   b. Treatment method is effective at safely treating dunnage, packaging, and other related materials that require treatment or specialized disposal.
   c. Treatment method will safely and effectively treat degradation products, impurities, cross-contaminants, and other inadvertent byproducts and constituents, including depleted uranium.

5. Short-term effectiveness:
   a. Treatment method can be implemented safely and quickly to replace the use of open burning/open detonation.

[1] Source: https://cswab.org/wp-content/uploads/2017/03/Cease-Fire-Campaign-Alternative-Technology-Criteria-FINAL.pdf.

6. Implementability:
   a. Treatment method is legal.
   b. Treatment method can be implemented within the federal and state environmental standards, regulations, and advisories.

7. State/territorial acceptance:
   a. Treatment method is supported by state or U.S. territorial government and environmental regulators.

8. Community acceptance:
   a. Treatment method is supported by local community leaders.
   b. Treatment method is supported by the affected community.
   c. Treatment method safety controls are supported by local first responders.
   d. Treatment method health and safety precautions are supported by onsite workers.

9. Environmental justice:
   a. Treatment method is supported by tribes and indigenous peoples who are both directly and indirectly impacted.
   b. Treatment method reflects and honors the cultural values of tribes and indigenous peoples who are both directly and indirectly impacted.
   c. Treatment method is not opposed by tribal government.
   d. Treatment method is not opposed by tribal elders.
   e. Treatment method offers maximum protection when evaluated in terms of indirect exposures. Examples include, but are not limited to, consumption of fish and wild game, and consumption and use of medicinal plants.
   f. Treatment method will achieve short-term and long-term compliance with tribal environmental regulations, standards, and health advisory levels.
   g. Treatment method offers maximum protection when evaluated in terms of disproportionate impact to disadvantaged, vulnerable, or susceptible populations.
   h. Treatment method offers maximum protection when evaluated in terms of cumulative, additive, and synergistic direct and indirect risks to residents, workers, onsite personnel, and others.
   i. Treatment method achieves compliance with Health Advisory Levels (or equivalent) when enforceable environmental standards are unavailable—for example, as with emerging contaminants.
   j. Treatment method does not put other global communities at risk.
   k. Treatment method will incentivize and encourage the development of advanced alternative technologies.

10. Transparency:
    a. The treatment method does not utilize “resource recovery,” “energy generation” or other incidental outcomes to avoid regulation under [the Resource Conservation and Recovery Act] and other applicable laws and regulations.
    b. The treatment method does not encourage rolling (successive) short-term emergency permits.
    c. All monitoring data is immediately published in an accessible format to assure that community members, workers, and soldiers are informed and empowered in the decision-making process.
    d. Details of how the technology and its pollution abatement systems work are fully disclosed to assure that community members, workers, onsite personnel, and soldiers are informed and empowered in the decision-making process.

C

Military Munitions Rule

In 1997 the Military Munitions Rule (MMR)[1] specifically declared that unused conventional munitions are not considered discarded until they are removed from storage to be treated. The MMR directly and unambiguously applies to the demilitarization of conventional explosive and reactive military munitions and directly governs how the Army must handle and move munitions or related materials (e.g., propellant) destined for treatment or destruction.

According to the MMR, an unused military munition becomes a solid waste when (1) the unused munition is "abandoned by being disposed of, burned, or incinerated, or treated prior to disposal"; (2) the unused munition is removed from storage for purposes of disposal or treatment prior to disposal; (3) the unused munition is deteriorated, leaking, or damaged to the point that it can no longer be returned to serviceable condition and cannot be reasonably recycled or used for other purposes (except, of course, recycling that is like "discard," i.e., placement on the ground, unless such placement is the result of use as a munition, or burning for energy recovery); or (4) the munition has been determined by an authorized military official to be a solid waste.[2] Therefore, in states that have adopted the MMR, stored unused munitions are not solid or hazardous waste until the material is finally removed from storage for the purpose of disposal or treatment prior to disposal.

The MMR does not apply to unused munitions that were buried or landfilled in the past, but would apply once those munitions are unearthed and further managed. In addition, the regulation does not apply to munitions being used for their intended purposes (e.g., military training). It also does not apply when a munition is destroyed during certain range clearance operations and when an unused munition, including components thereof, is repaired, reused, recycled, reclaimed, disassembled, reconfigured, or otherwise subjected to materials recovery activities.[3] However, except for the type of exemptions discussed herein, the ultimate treatment or destruction of waste military munitions must be conducted under a Resource Conservation and Recovery Act (RCRA) permit.

Six of the pertinent stockpile depot states have regulations governing waste military munitions that are substantially equivalent to the federal program: Alabama,[4] Indiana,[5]

[1] The term "military munitions" means all ammunition products and components produced or used by or for the U.S. Department of Defense (DoD) or the U.S. Armed Services for national defense and security, including military munitions under the control of the Department of Defense, the U.S. Coast Guard, the Department of Energy, and National Guard personnel. Military munitions include confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, smokes, and incendiaries used by DoD component organizations, including bulk explosives and chemical warfare agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof. Military munitions do not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components thereof. However, the term does include nonnuclear components of nuclear devices, managed under the Department of Energy's nuclear weapons program after all required sanitization operations under the Atomic Energy Act of 1954, as amended, have been completed. 40 Code of Federal Regulations (CFR) Part 266, Subpart M, § 260.10.

[2] 40 CFR Part 266, Subpart M, § 266.202(b)(1)-(4).

[3] EPA, "Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Manifest Exemption for Transport of Hazardous Waste on Right-of-Ways on Contiguous Properties," Federal Register, Vol. 62, No. 29, February 12, 1997, p. 6628 and 6629, and 40 CFR 266.202(a)(2).

[4] Alabama Department of Environmental Management, Admin. Code r. 335-14-5-.31 and 225-14-6-.31.

[5] Indiana Department of Environmental Management, Title 329 Article 3.1 of the Indiana Administrative Code, 329-3.1-11-1.

Kentucky,[6] Nevada,[7] Oklahoma,[8] and Pennsylvania.[9] Only Utah has not adopted the MMR provisions. The MMR does not have provisions for citing or permit conditions for RCRA conventional munitions demilitarization sites or units. The MMR's only impact on the conventional munition demilitarization program is the timing for munitions to be declared hazardous waste and the shipment of munitions on public highways (e.g., no RCRA manifest is required). It also may provide support for RCRA exemption applications for units where munitions are repaired, reused, recycled, reclaimed, disassembled, reconfigured, or otherwise subjected to materials recovery activities (e.g., not treating a solid or hazardous waste).

[6] Kentucky Department for Environmental Protection, 401 Kentucky Administration Regulations 36:080. Military munitions.

[7] Nevada Department of Environmental Protection, Nevada Administrative Code 444.8632.

[8] Oklahoma Department of Environmental Quality, Oklahoma Environmental Quality Code, 2525:205-3-2(h).

[9] Pennsylvania Department of Environmental Protection, Pennsylvania Code Title 25 Chapter 266a.20.

D

Public Concerns About Open Burning/Open Detonation and Alternative Demilitarization Options

This appendix summarizes information provided to the committee by public interest group representatives, including members of the Cease Fire! Campaign. Cease Fire! Campaign is a national coalition of more than 60 local groups that is a leading opponent of open burning (OB) and open detonation (OD). Understanding the basis for public concerns can play an important role in building support for proposals for implementing alternative technologies at specific facilities and communities. Failing to adequately address these concerns, on the other hand, could undermine support for promising methods of treatment, which could affect the ability of the Army to achieve its stated goal of increasing the use of alternative technologies in lieu of OB/OD. The reporting of the concerns of the public interest groups in this appendix does not imply any agreement or disagreement by the committee.

In their written presentations and verbal comments, public interest group representatives

- Described their concerns about OB/OD and a stated objection to OB/OD wherever it occurs;
- Expressed their support for identifying and using alternative technologies in lieu of OB/OD wherever possible; and
- Provided a list of criteria for decision makers to use in designing, evaluating, and selecting alternative technologies (presented in Appendix B).

The criteria and other input to the committee (e.g., "Camp Minden Dialogue Process," Facilitators' Report, March 15, 2015) are informed by the representatives' experiences as neighbors of facilities that use OB and OD; by their experiences with waste incineration facilities; and by their experiences with the technology selection and decision-making processes used by other agencies, such as the U.S. chemical weapons demilitarization program. Notably, the majority of comments and written documents submitted by Cease Fire! members about OB/OD addressed facilities other than the seven stockpile depots that are the focus of this study. Indeed, as stated by the Joint Munitions Command chief of public affairs, there is very little overt controversy or opposition at the seven stockpile sites involved in conventional munitions demilitarization. Opposition appears to be most prevalent at Army munitions production sites, as well as at other federal agency (e.g., Department of Energy) sites where OB/OD is being carried out. However, members of the Cease Fire! Campaign are active at both the national and local levels, and as demonstrated in their presentations and documents, their concerns could impact activities at the seven stockpile sites that are the focus of this study.

The concerns expressed by representative of public interest groups are based on three intertwined issues:

1. The characteristics of a technology and associated risks (e.g., the potential for catastrophic releases, the familiarity of a technology and its risks, types of secondary wastes generated, pollution abatement methods, distribution of risks and benefits within and among communities);
2. The management of the technology (e.g., information is publicly available about how the technology and its pollution abatement system work, monitoring data are immediately available and accessible); and
3. The processes for making decisions (e.g., whether they are viewed as being fair, transparent, and based on accepted and appropriate criteria).

Concerns expressed by the representatives are not limited to a particular treatment method; rather, they extend to the full demilitarization system and its management, which includes handling, storage, processing of material, treatment and disposal of secondary wastes, and intersite transportation of munitions and wastes.

CONCERNS ABOUT DEMILITARIZATION TECHNOLOGIES

The potential public health and environmental risks of treatment technologies are a primary concern expressed by those providing input to the committee. Their perceptions about these risks are a major contributor to public opposition to OB/OD and also the impetus of this report. These perceptions could also be the basis for supporting some alternative technologies *and* apprehension about other alternatives, such as incineration. For example, the Cease Fire! Campaign states that it "seeks to protect human health and the environment by calling for the immediate implementation of safer alternatives to open air burning, detonation, and non-closed loop incineration/combustion of military munitions."[1]

Specific concerns that were expressed to the committee about designing, evaluating, and selecting alternative technologies include the following:

- The potential for contamination of surface and groundwater, soil, and air resulting from treatment activities. These concerns include the potential for both acute and chronic risks and impacts to the public, especially for vulnerable populations and those living close to the site. They include, for example, exposures from air emissions from specific events as well as cumulative and long-term risks from repeated exposures.[2]
- Nuisance risks that communities have experienced from OB/OD. These include property damage from vibration and blasts (e.g., broken windows and broken dishes), noise, odors, and dust.
- Inability to monitor and characterize emissions. Concerns about inadequate monitoring and the continuation of a long-standing concern about incineration emissions were very evident. As discussed in the following section, the ability to monitor and characterize a technology's emissions is also closely linked with public confidence in the management process and in assuring the public that public health risks to the surrounding community are fully identified and evaluated.
- Redistribution of risks resulting from the increased transportation of munitions from one site to another to facilitate the use of non-OB/OD treatment methods or the selection of a technology that would require the shipment of secondary wastes, such as brine, to a subsequent site for final treatment. As stated in the presentations of Cease Fire! members to the committee, their opposition to shipment is based on global perceptions of harm and unfair redistribution of risks to receiving communities.

Although the representatives identified potential alternatives to OB/OD that have been developed or deployed, they do not necessarily endorse or support any one of these technologies; rather they want an assessment of alternatives, conducted independently of the Army, to assure communities of their safety. Their goal is for any assessment to "use their criteria to assess the technologies, then allow each community to decide what is important to them."[3] They recognize that all of the criteria do not need to be met before selecting a technology; rather that the criteria are aspirational and provide a list of issues that should be explicitly considered. For example, site-specific considerations could include proximity to nearby residents, proximity to tribal land, and demographics of nearby populations, including growth and encroachment of populations over time. In addition, physical characteristics may be relevant. Although controversial, one representative of the public commented to the committee that thermal treatment with pollution abatement is worth considering, especially if other alternatives to OB/OD require large volumes of water in water-scarce areas.

CONCERNS ABOUT THE RISK MANAGEMENT AND DECISION PROCESSES RELATED TO OB/OD AND ALTERNATIVE DEMILITARIZATION TECHNOLOGIES

Concerns expressed to the committee by representatives of public interest groups about the technical risks of technologies are closely interwoven with their concerns about the management of risks and decision-making processes associated with conventional demilitarization technologies. Although controversy and opposition appears to be concentrated at Army sites such as production sites that are not the focus of this study, their experiences with OB/OD in multiple contexts beyond the seven demilitarization sites color their views of Army management of conventional munitions demilitarization.

The intertwining of technical and management concerns is most clearly demonstrated in discussions about monitoring. In many statements public representatives revealed an underlying lack of confidence that emissions monitoring will be adequate to protect human health. As one representative emphasized, "A lot of what the community acceptance is about is about monitorability and our ability to know what is actually going on," and:

[1] For information about the Cease Fire! Campaign, see https://cswab.org/cease-fire-campaign/about-the-campaign.

[2] While not within the scope of this study, the representatives also expressed concerns about the risks to public health and the environment posed by legacy wastes at sites with ongoing operations. They believe that residual contamination and unexploded ordinance within site perimeters may prevent a comprehensive identification and evaluation of the risks from current or future operations.

[3] J. Williams, executive director, California Communities Against Toxics, and F. Kelley, member, steering committee, Cease Fire! Campaign, "Presentation to the National Academy of Sciences Committee on Alternatives for the Demilitarization of Conventional Munitions," presentation to the committee, October 23, 2017.

> Monitorability is very critical because that's how we know what is actually happening. Everything can be perfect on paper but as we all know, if it's not operated correctly, there's something else that happens, [and] what you thought were the emissions may not be what the actual emissions are.[4]

The importance of monitoring all emissions, exemplified by technologies that can "hold, test, and release" (i.e., characterize all wastes—solid, liquid, or gas—before release), has long been emphasized by some members of the coalition.

Public interest group representatives expressed little confidence that the management of demilitarization activities will ensure protection of the public. As indicated in their expectation of an independent review by the committee, they believe that contractors' evaluations and reports are subject to conflicts of interest and that state regulators lack the expertise and resources to effectively evaluate and monitor Army demilitarization activities. Comments received by the committee indicate that the loss of trust and confidence expressed by public interest group members is compounded by their past experiences related to other military programs—in particular, with the early phases of the chemical weapons demilitarization program, prior to the Assembled Chemical Weapons Assessment dialogue process. While many of their experiences have been at sites that are not the focus of this study, public interest group representatives expressed to the committee a general view that the Army's actions and perceived failure to respond to public concerns have created an adversarial atmosphere at sites that are conducting OB/OD operations.

Additional concerns expressed by public interest groups and members of the public related to the management of demilitarization of munitions are reflected in their general views about Army management of OB and OD at various sites, and include their beliefs that

- Information provided to the public has been, at times, inconsistent or inaccurate.
- There has been a lack of opportunities for public involvement.
- There has been inadequate effort by the Army to investigate public concerns, including consideration of risks to vulnerable populations in decision making and a lack of transparency.
- The full costs of OB/OD, including environmental impacts, health impacts, and site remedial activities have not been taken into account.
- There has not been a serious effort by the Army to seek and use alternatives to OB/OD more broadly, as demonstrated by perception that
    - The distinctions among different types of munitions and "accounts is artificial and bureaucratic";[5]
    - The responsibility for transitioning to alternative technologies is fragmented, especially with regard to public interactions; and
    - There is a lack of funding for the implementation and research and development of alternative technologies.

At the same time, the committee was provided with information suggesting that public acceptance of alternative technologies, even when viewed as risky, may be possible when decision processes are responsive to community concerns and promote shared learning. This point is demonstrated by the experience at Camp Minden and with experiences with the U.S. chemical weapons demilitarization program (EPA, 2015, Attachment A). While Camp Minden is not one of the seven stockpile depots being studied, it is significant because of the active role played by the community in providing input into the state of Louisiana's selection of an alternative technology for the treatment of 15 million lb of bulk propellant improperly stored at a contractor's site, resulting in a significant safety hazard. The example is also significant in illustrating the way in which decision making based in technical evaluations is intertwined with public confidence in management process, especially transparency. Significant public outcry resulted in the reversal of the initial decision to treat the propellant by OB and the design of a decision-making process to quickly help the community, local officials, and regulators identify and evaluate alternative technologies to deal with the complex, emergency situation, even without full information about pollution abatement. The process of arriving at a solution involved a mixture of technical and process actions designed to improve, and assure the community of, process safety and the transparency of decisions;[6] dialogue among stakeholders; information about the constituents and magnitudes of releases from the system's pollution abatement system to the environment; methods implemented to ensure that the

[4] Ibid.

[5] The public interest groups that oppose OB/OD had anticipated that the congressionally mandated statement of task governing this study would encompass a broader scope and include all Army sites using OB/OD to treat waste munitions, bulk energetics, and associated wastes. While the committee acknowledges the groups' concerns about the scope of the study, the committee was limited in its work to the sites addressed by the statement of task.

[6] R. Hayes, president, El Dorado Engineering, "El Dorado Engineering's Technologies for the Demilitarization of Conventional Munitions," presentation to the committee, October 24, 2017; J. Williams, executive director, California Communities Against Toxics, and F. Kelley, member, steering committee, Cease Fire! Campaign, "Presentation to the National Academy of Sciences Committee on Alternatives for the Demilitarization of Conventional Munitions," presentation to the committee, October 23, 2017; L. Siegel, executive director, Center of Public and Environmental Oversight, "Communities and Conventional Munitions Demilitarization," presentation to the committee, August 23, 2017.

releases were monitored; independent experts from trusted sources who were able to observe tests and share information with the public in a way understandable to them; and a contractor open to scrutiny and responsive to questions and concerns (EPA, 2015). In the words of one public interest group representative who spoke about the Camp Minden experience at the Committee meeting:

> Transparency is *so* critical. … There was a lot of distrust of [the Environmental Protection Agency], distrust of [the Department of Defense], distrust of our state government when we started and then we were able come to the table, arrive at a solution and build trust with each other. And a lot of that [trust] was built on every step of this process was going to be transparent—whatever technology was implemented, we wanted it to be fully transparent, we wanted to know how would the pollution abatement system work, how would they test for various emissions, how would we know that everything was operating the way it was designed to operate.[7]

The focus on transparency and other process features described above helped to build trust and acceptance of the selected treatment technology. The urgency of the situation also contributed to public acceptance of the technology used at Camp Minden by placing a premium on selecting an "off the shelf" technology that had already received approval by the regulators and the Department of Defense and could be implemented immediately.[8] It also encouraged agreement among the various parties, even though the particular technology selected was not necessarily the preferred choice of every participant (EPA, 2015).[9] Also significant, consistent with community members' opposition, the state governor subsequently did not allow the facility to become permanent.[10]

In summary, the committee heard from comments and presentations from public interest groups that there is significant, national-level public opposition to the continued use of OB/OD. While there is general support for seeking and using alternative technologies that are perceived as having less public health and environmental risk, support is context-specific, as opposition may arise about particular alternative technologies in specific communities. Understanding the basis for public concerns can play an important role in building support for proposals for alternative technologies at specific facilities and communities, while failure to adequately address them could undermine support for promising methods of treatment. This, in turn, could affect the ability of the Army to achieve its stated goal of increasing the use of alternative technologies.

REFERENCE

EPA (U.S. Environmental Protection Agency). 2015. "Results of the Camp Minden Dialogue Process, Facilitators' Report, March 13, 2015." https://www.epa.gov/sites/production/files/2015-03/documents/camp_minden_dialogue_facilitators_report_final_3_13_15_0.pdf.

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[7] J. Williams, executive director, California Communities Against Toxics, and F. Kelley, member, steering committee, Cease Fire! Campaign, "Presentation to the National Academy of Sciences Committee on Alternatives for the Demilitarization of Conventional Munitions," presentation to the committee, October 23, 2017.

[8] J. Williams, executive director, California Communities Against Toxics, panel discussion on October 23, 2017.

[9] F. Kelley, member, steering committee, Cease Fire! Campaign, panel discussion on October 23, 2017.

[10] More Questions Over the Future of Camp Minden Burn Chamber, https://www.ktbs.com/news/arklatex-indepth/more-questions-over-the-future-of-the-camp-minden-burn/article_64e58c2c-05c7-11e8-a329-472c9a69530b.html.

E

Committee Biographical Information

TODD A. KIMMELL, *Chair*, is a principal investigator with the Environmental Science Division at the U.S. Department of Energy (DOE) Argonne National Laboratory. Mr. Kimmell is an environmental scientist and policy analyst, with more than 35 years' experience in solid and hazardous waste management, permitting and regulatory compliance, cleanup programs, environmental programs policy development, and emergency management and homeland security. He has supported the Army's chemical and conventional munitions management programs, and has contributed to the Army's Assembled Chemical Weapons Alternatives Program and the Chemical Stockpile Emergency Preparedness Program. Mr. Kimmell also has a strong technical background in analytical and physical/chemical test method development, and analytical quality assurance and control. He has served the U.S. Environmental Protection Agency (EPA) National Homeland Security Research Center on environmental test methods for chemical, biological, and radiological assessment for emergency response. He was involved in the Army's first coordinated effort to permit open burning/open detonation (OB/OD) operations nationwide, supported the Pentagon's Operational Executive Environmental Steering Committee for Munitions and contributed to several Department of Defense (DoD) manuals, including the *Military Munitions Rule Implementation Procedures Manual* and *Management and Disposition of Material Potentially Presenting an Explosive Hazard Procedures Manual*. Mr. Kimmell has also supported a number of environmental permitting programs at Army chemical weapons storage sites and at OB/OD sites. He graduated from George Washington University with an M.S. in environmental science.

DOUGLAS M. MEDVILLE, *Vice Chair*, retired from MITRE as program leader for chemical materiel disposal and remediation. Mr. Medville has led many analyses of risk, process engineering, transportation, and alternative disposal technologies and has briefed public and senior military officials on the results. Mr. Medville was responsible for evaluating the reliability and performance of the demilitarization machines used by the Army to disassemble stockpile chemical munitions and wrote several test plans and protocols for alternative chemical munition disposal technologies. He also led the evaluation of the operational performance of the Army's chemical weapon disposal facility on Johnson Atoll and directed an assessment of the risks, public perceptions, environmental aspects, and logistics of transporting recovered non-stockpile chemical warfare materiel to candidate storage and disposal destinations. Before that, he worked at Franklin Institute Research Laboratories and General Electric. Mr. Medville earned a B.S. in industrial engineering and an M.S. in operations research, both from New York University.

JUDITH A. BRADBURY is a retired technical manager from Battelle, Pacific Northwest National Laboratory. Dr. Bradbury graduated from the University of Pittsburgh with a Ph.D. in public and international affairs and has an M.A. in public affairs from the Indiana University of Pennsylvania and a B.S. in sociology from the London School of Economics. In her work, she has emphasized the relevance of social science insights and tools to the analysis and resolution of science policy issues. She has extensive experience in both the practice and research of public involvement and institutional activities. Her experience includes responsibility for planning and implementing outreach and education activities for the Midwest Regional Carbon Sequestration partnership. Previous work includes evaluation of selected U.S. Army Restoration Advisory Boards; a series of evaluations of the effectiveness of the Department of Energy (DOE) Site-Specific Advisory boards; evaluation of a training program in public participation for DOE managers; meeting facilitation, planning, and program evaluation for the DOE nuclear waste transportation program; and research into community perspectives of the risks of incineration for disposing of the nation's stockpile of chemical weapons.

GAIL CHARNLEY is the principal at HealthRisk Strategies, LLC. Dr. Charnley is an internationally recognized scientist specializing in environmental health risk assessment and risk management science and policy. She has 30 years of experience in the biological, chemical, and social policy aspects of environmental and public health protection, writing and speaking extensively on issues related to the roles of science and risk analysis in environmental and public health risk management decision making. Dr. Charnley focuses on strategic analysis and risk communication of complex scientific and regulatory issues to both nontechnical and scientific audiences. She works primarily on the safety of chemicals in food, environmental media, work environments, and consumer products. She served two terms on the National Academies of Sciences, Engineering, and Medicine's Board on Environmental Studies and Toxicology, and she served on the Army Science Board, for which she chaired numerous committees and was responsible for managing the conduct of critical evaluations of the Army's environmental and toxicological practices. She has also served on numerous peer review panels convened by the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and Health and Welfare Canada. From 1994 to 1997 she was executive director of the Presidential/Congressional Commission on Risk Assessment and Risk Management, mandated by Congress to evaluate the roles that risk assessment and risk management play in federal regulatory programs. Before her appointment to the commission, she worked at the National Research Council (NRC) and served as acting director of the Toxicology and Risk Assessment Program at the NRC. Dr. Charnley holds an A.B. in biochemistry from Wellesley College and a Ph.D. in toxicology from the Massachusetts Institute of Technology.

HEREK L. CLACK is a research associate professor in the Department of Civil and Environmental Engineering at the University of Michigan. Previously, Dr. Clack was an associate professor in the Mechanical, Materials, and Aerospace Engineering Department at the Illinois Institute of Technology (IIT). He received his B.S. in aeronautical and astronautical engineering from the Massachusetts Institute of Technology (1987), and his M.S. (1997) and Ph.D. (1998) in mechanical engineering from the University of California, Berkeley. Prior to joining the IIT faculty, Dr. Clack was a National Research Council (NRC) postdoctoral fellow in residence at the National Institute of Standards and Technology in Gaithersburg, Maryland (1998-1999) and a member of the technical staff at the Rocketdyne Division of Boeing Corporation (1987-1992). He is engaged in research and publication in the areas of emission and control of air pollutants, aerosols, nonthermal plasmas, and transport phenomena within dispersions.

DEBORAH L. GRUBBE is the owner and president of Operations and Safety Solutions, LLC. Previously, Ms. Grubbe was vice president of safety change management at BP, where she was accountable to establish overall safety leadership and cultural improvement for five U.S. refineries. Prior to that, Ms. Grubbe was the vice president of group safety at BP in London, where she assessed, developed, and executed the group safety strategy. Ms. Grubbe graduated with a B.S. in chemical engineering with highest distinction from Purdue University. She received a Winston Churchill Fellowship to attend Cambridge University in England, where she received a Certificate of Post-Graduate Study in Chemical Engineering. She is a registered professional engineer in Delaware. Ms. Grubbe has been a member of several National Academies of Sciences, Engineering, and Medicine committees related to the demilitarization of chemical weapons, including *Closure and Johnston Atoll Chemical Agent Disposal System Report* (National Academies, 2002), authored by the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program.

REBECCA A. HAFFENDEN currently serves part-time as a program's attorney at Argonne National Laboratory through Global Empire, LLC. Ms. Haffenden's professional experience has included work for the U.S. Department of Homeland Security to evaluate legislation and regulations associated with security vulnerabilities and providing legal expertise to programs involving federal facility site remediation and hazardous waste compliance and corrective actions under the Resource Conservation and Recovery Act (RCRA). She also co-authored a working paper on the application of federal and state hazardous waste regulatory programs to waste chemical agents, in addition to being a co-author of the Environmental Impact Statement for the Assembled Chemical Weapons Alternatives program. Ms. Haffenden has served on several National Academies of Sciences, Engineering, and Medicine chemical demilitarization committees, providing critical permitting and environmental law expertise and drafting key parts of the reports. Ms. Haffenden received a B.A. in psychology from the University of Illinois at Urbana–Champaign, and a J.D. from Suffolk Law School, Boston.

PETER R. JAFFE is a professor of civil engineering and environmental engineering in the Department of Civil and Environmental Engineering and the associate director for research at the Andlinger Center for Energy and the Environment at Princeton University. Dr. Jaffe's research interests relate to the physical, chemical, and biological processes that govern the transport and transformation of pollutants in the environment and their application toward the remediation of contaminated systems. Dr. Jaffe received a B.S. in chemical engineering from the Universidad Simón Bolívar in Caracas, Venezuela, and an M.S. and a Ph.D. in environmental and water resources engineering from Vanderbilt University in 1980 and 1981, respectively.

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LAWRENCE J. WASHINGTON is a retired corporate vice president for Sustainability and Environmental Health and Safety (EH&S), who worked for the Dow Chemical Company for more than 37 years. Among his many distinctions, Mr. Washington chaired the Corporate Environmental Advisory Council and the EH&S Management Board and the Crisis Management Team. He also served as an officer of the company. In his previous role as corporate vice president, EH&S, Human Resources and Public Affairs, Mr. Washington led the creation of the Genesis Award Program for Excellence in People Development. His career within Dow included many roles in operations, including leader of Dow's Western Division and general manager and site leader for Michigan operations. Mr. Washington has also served on National Academies of Sciences, Engineering, and Medicine chemical demilitarization committees from 2008 to 2012. Mr. Washington earned bachelor's and master's degrees in chemical engineering from the University of Detroit.

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Acronyms

AED	Ammunition Equipment Directorate
AMCOM	Aviation and Missile Command
ANAD	Anniston Army Depot
ANMC	Anniston Munitions Center
AoA	analysis of alternatives
AP	ammonium perchlorate
APCS	air pollution control system
APE	ammunition peculiar equipment
ARMD	Ammonium Perchlorate Rocket Motor Destruction facility
BEDS	Bulk Energetics Disposal System
BGAD	Blue Grass Army Depot
BGCAPP	Blue Grass Chemical Agent Destruction Pilot Plant
CAA	Clean Air Act
CAAA	Crane Army Ammunition Activity
CAD	cartridge actuated device
CB	contained burning
CBI	Clean Burning Igniter
CD	contained detonation
CDC	Controlled Detonation Chamber
CDT	contained disposal technology
CFR	Code of Federal Regulations
COCO	contractor owned, contractor operated
CWM	chemical warfare material
CWP	Contaminated Waste Processor
DAVINCH	Detonation of Ammunition in a Vacuum Integrated Chamber
DDESB	Department of Defense Explosives Safety Board
DoD	Department of Defense
DODIC	Department of Defense Identification Code
DOE	Department of Energy
DU	depleted uranium
EDS	Explosive Destruction System
E-ILS	Enterprise Integrated Logistics Strategy
EPA	Environmental Protection Agency
EWI	Explosive Waste Incinerator
FDA	Food and Drug Administration
FMEA	failure modes and effects analysis
FTE	full-time equivalent
GAO	Government Accountability Office
GOCO	government owned, contractor operated
GOGO	government owned, government operated
HC	hexachloroethane
HE	high-explosive
HEAT	high-explosive anti-tank
HHERA	Human Health and Ecological Risk Assessment
HWAD	Hawthorne Army Depot
ID	induced draft
iSCWO	industrial supercritical water oxidation
JMC	Joint Munitions Command
LCC	life cycle cost
LEAD	Letterkenny Army Depot
LEMC	Letterkenny Munitions Center
LMP	Logistics Modernization Program
MACT	maximum achievable control technology
MCAAP	McAlester Army Ammunition Plant
MIDAS	Munitions Items Disposition Action System
MLRS	Multiple Launch Rocket System
MMR	Military Munitions Rule

NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NEW	net explosive weight
NRC	National Research Council
OB	open burn/open burning
OD	open detonation
OSD	Office of the Secretary of Defense
PAD	propellant actuated device
PAS	pollution abatement system
PCH	packing, crating, and handling
PD Demil	Office of the Product Director for Demilitarization
PM	particulate matter
PODS	Plasma Ordnance Demilitarization System
PPE	personnel protective equipment
QASAS	Quality Assurance Specialist (Ammunition Surveillance)
R3	reclamation, recycling, and reuse
RAMSLIC	remote automated motor sealing, loading, and ignition completion
RCRA	Resource Conservation and Recovery Act
RDT&E	research, development, testing, and evaluation
RKI	rotary kiln incinerator
SAA	small arms ammunition
SDC	Static Detonation Chamber
SMCA	Single Manager for Conventional Ammunition
SOP	standard operating procedure
SOT	statement of task
TAMR	Total Army Munitions Requirement
TEAD	Tooele Army Depot
TFF	Transportable Flashing Furnace
TRL	technology readiness level
TSDF	treatment, storage, and disposal facility
TTC	thermal treatment chamber
TTCDP	thermal treatment closed disposal process
UXO	unexploded ordnance
VOC	volatile organic compound