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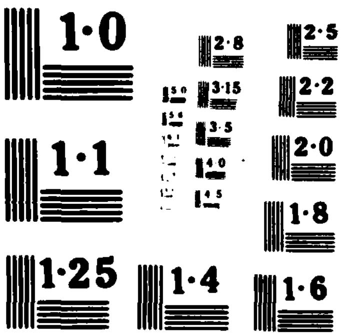
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This report presents an economic analysis of waste management options for obsolete and unserviceable conventional ammunition. Five options were considered:

- thermal treatment by open-field detonation;
- removal of explosives from munition hardware by the hot water washout/steamout process, followed by incineration of all energetic components and thermal treatment of metallic hardware;
- removal of explosives from munition hardware by the meltout process, followed by incineration of all energetic components and thermal treatment of metallic hardware·
- removal of explosives from munition hardware of the hot water washout/steamout process, followed by refining of recovered explosives and thermal treatment of metallic hardware; and
- removal of explosives from munition hardware by the meltout process, followed by refining of recovered explosives and thermal treatment of metallic hardware.

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The economic analysis focussed on five representative obsolete and unserviceable munitions:

- 90-mm cartridges filled with TNT or Composition B;
- 3.5-inch rockets filled with Composition B;
- 5-inch rocket warheads filled with TNT or Composition B;
- MK-9 depth charges filled with TNT; and
- the TNT-filled M59A1 semi-armor piercing bomb.

A generic capital and operating cost data base was developed for the thermal treatment of or the recovery of resources from these munitions. This data base was applied in a case study of the relative economic attractiveness of the five waste management options.

The case study conclusively showed that thermal treatment of obsolete and unserviceable conventional munitions by open-field detonation provides significant capital and operating cost advantages over the other waste management practices that were considered.

The capital investment required to implement a resource recovery program was found to be approximately 75% of the capital investment for a controlled disposal program; the overriding factor contributing to these cost differences is the high cost of explosives incineration equipment.

The operating and maintenance costs for resource recovery are about half the costs associated with controlled disposal. This is because resource recovery gives a sizeable cost savings due to credits attributed to the value of the recovered explosives and propellants.

Thus, if open-field burning and detonation cannot be practiced in the future, recovery of explosives and other resources from obsolete and unserviceable munitions is projected to offer the most economical means of managing these wastes.

Report to

United States Army
Toxic and Hazardous
Materials Agency
May 1986

Economic Analysis of the Recovery and Reuse of Explosives from Obsolete and Unserviceable Conventional Ammunition

Final Report

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TABLE OF CONTENTS

SECTION 1

EXECUTIVE SUMMARY

This report presents an economic analysis of waste management options for obsolete and unserviceable conventional ammunition. Five options were considered:

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- removal of explosives from munition hardware by the hot water washout/steamout process followed by incineration of all energetic components and thermal treatment of metallic hardware;
- removal of explosives from munition hardware by the meltout process followed by incineration of all energetic components and thermal treatment of metallic hardware;
- removal of explosives from munition hardware by the hot water washout/steamout process followed by refining of recovered explosives and thermal treatment of metallic hardware; and
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The economic analysis focussed on five representative obsolete and unserviceable munitions:

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A generic capital and operating cost data base was developed for the thermal treatment of or recovery of resources from these munitions. This data base was applied in a case study of the relative economic attractiveness of the five waste management options listed above.

The five munitions considered in the case study are currently stored at eight Army installations. The stockpile is not evenly distributed among the installations. Additionally, each installation has some equipment or facilities that could be used to implement each of the waste management operations. Consequently, the case study had to account for the distribution of munitions and waste management facilities at the eight installations.

The case study conclusively showed that thermal treatment of obsolete and unserviceable conventional munitions by open field detonation provides significant capital and operating cost advantages over the other waste management practices that were considered. The cost differences are illustrated by the data below:

	Capital Cost ($ '000,000)	First Year Operating Cost ($ '000,000/yr)
Open Detonation	0.6	2.3
Resource Recovery	56.7 - 58.8	4.8 - 5.8
Controlled Thermal Destruction	74.5 - 77.1	10.6 - 11.4

It is important to note that the thermal treatment of obsolete and unserviceable conventional ammunition is regulated by RCRA, as well as by laws imposed by state and local governments. At present, the Interim Status Standards promulgated under RCRA allow the Army to practice open burning and open detonation of waste explosives and propellants. It should be noted that the final RCRA standards are expected to be imposed within the next few years, and it is not certain that continuation of thermal treatment practices will be allowed under the final standards. Even if the final Federal regulations allow for open field detonation and burning of waste explosives, state and local governments could take action to prohibit these practices. This has already occurred in Nevada and Kentucky, where HWAAP and LBAD, respectively, were denied renewal of their permits for open burning and open detonation of conventional military materiel.

If open burning and open detonation cannot be practiced in the future, which is a definite possibility given the current environmental climate, resource recovery has certain economic advantages over controlled disposal. These can be summarized as follows:

- The capital investment required to implement a resource recovery program was found to be approximately 75 percent of the capital investment for a controlled disposal program; the overriding factor contributing to these cost differences is the high cost of explosives incineration equipment.

- The operating and maintenance costs for resource recovery are about half the costs associated with controlled disposal. This is due primarily to two factors:

  - Resource recovery realizes a sizable cost savings due to credits attributed to the value of recovered explosives and propellants.

- The operating and maintenance costs associated with the operation of a bulk explosives incinerator (which is unique to the control disposal option) are significant.

Thus, if open field burning and detonation cannot be practiced in the future, recovery of explosives and other resources from obsolete and unserviceable munitions is projected to offer the most economic means of managing these wastes.

SECTION 2

INTRODUCTION

2.1 BACKGROUND

The Department of the Army (DA), as the single service manager of Department of Defense (DOD) ammunition, is responsible for the disposal of obsolete and unserviceable high explosive materiel. In recent years, disposal of high explosive munitions has become increasingly complicated due to heightened environmental awareness and resulting legislation. Until the early 1970's, munitions were disposed of by open sea dumping. However, the Marine Protection, Research and Sanctuaries Act of 1972 was passed "...to prevent or strictly limit the dumping into ocean waters of any material that would adversely affect human health, welfare or amenities, or the marine environment, ecological systems, or economic potentialities." (1) In particular, the act restricted ocean disposal of DOD materiel, and, as a result, open field burning and detonation became the dominant methods of destroying obsolete or unserviceable high explosive munitions. However, even these practices are now subject to increasing environmental regulation restrictions.

The regulations promulgated under the Resource Conservation and Recovery Act (RCRA), as amended in 1984, prohibit open burning of hazardous waste, "...except for the open burning and detonation of waste explosives. Waste explosives include waste which has the potential to detonate and bulk military propellants which cannot be disposed of through other modes of treatment." (2) While the current Federal regulations exempt high explosive military materiel from such controls and allow disposal of these items by open field burning and detonation, the future could bring increased environmental restrictions in the form of new federal regulations. The Ammunition Equipment Directorate of Tooele Army Depot (TEAD) is presently working in close conjunction with the Federal Environmental Protection Agency (EPA) on a project aimed at characterizing emissions and residues from open burning/open detonation. It is their hope that this project will identify environmentally sound open burning/open detonation methods that EPA can incorporate as standards in RCRA, thereby allowing the continuation of these thermal treatment practices. (3)

It must be noted that state and local governments are allowed to impose restrictions on hazardous waste disposal that are more stringent than the Federal regulations. Such future restrictions could potentially affect open burning and open detonation at many Army installations. Some states or localities may refrain from issuing environmental permits for open burning and open detonation; this has already been the case at two Army installations: Hawthorne Army Ammunition Plant (HWAAP) and Lexington Blue Grass Army Depot (LBAD). (3)

The intent of RCRA is to promote a reduction in hazardous waste disposal through increased recovery of useful resources, while ensuring that any necessary hazardous waste disposal operations are environmentally sound. Thus, the recovery of high explosives from obsolete and unserviceable munitions is consistent with the intent of RCRA, and may be an attractive alternative to thermal treatment of these items. The Army has adopted this philosophy and has given top priority to recovery and reuse of high explosives from obsolete and unserviceable munitions. (4,5)

2.2 OBJECTIVE

This study was undertaken to evaluate the economic feasibility of recovering and reusing high explosives from obsolete and unserviceable munitions. The costs of recovery processes were compared with the costs of thermal treating high explosive materiel by open field burning/detonation and by controlled methods (i.e., incineration).

2.3 SCOPE OF WORK

The United States Army Toxic and Hazardous Materials Agency (USATHAMA) directed this study. State-of-the-art recovery/reuse processes were identified, and generic cost estimates were developed for these processes. State-of-the-art technology for thermal treatment of high explosive munitions (i.e., open burning/detonation and incineration) were also surveyed, and generic cost estimates were developed for these schemes. A case study was subsequently completed, in which the cost of high explosives recovery/reuse was compared to the costs of conventional thermal treatment practice (i.e., open-field burning/detonation) as well as to the costs of controlled thermal treatment methods.

The use of energetic materials as fuel supplements was not addressed in this study.

SECTION 3

WASTE EXPLOSIVES MANAGEMENT OPTIONS

3.1 INTRODUCTION

There are numerous approaches to management of obsolete and unserviceable high explosive munitions, including:

- open field burning/detonation;
- controlled thermal methods; and
- resource recovery/reuse.

Within these broad categories of waste explosives management options there exist numerous technology variations.

Open burning and open detonation of obsolete and unserviceable high explosive munitions differ significantly from the other alternatives considered in this study. The first portion of this section (Section 3.2) describes these alternatives. Disposal of obsolete high explosive munitions by controlled thermal methods involves a complex series of technical operations, as does explosives recovery. Examination of these two alternatives indicates that a significant number of identical operations are embodied in each alternative, as shown in Figure 3-1. Consequently, a modular approach was followed in describing the components of these systems. These modules can be grouped into four distinct classifications: 1) Mechanical Processing Operations; 2) Explosive Recovery Operations; 3) Recovered Explosives Refining Operations; and 4) Thermal Treatment Operations. Descriptions of these four modules comprise Section 3.3.

3.2 OPEN BURNING/OPEN DETONATION

Open burning can only be conducted at specially prepared sites or pads under favorable meteorological conditions. It can be applied to a variety of energetic materials including loose, bulk propellants, explosives and pyrotechnics. A few thousand pounds of the loose energetic material would be spread in a layer less than three inches deep; this layer would be placed on a bed of highly combustible material. This arrangement insures that complete combustion of the energetic material takes place. The bed would be ignited by a safety fuze or electric squib. (5)

Some munitions are also amenable to thermal treatment by open burning, particularly open-ended high explosive loaded projectiles from which the explosive fill can be burned without inducing a detonation. Predetermined quantities of open-ended projectiles would be placed side-by-side, and combustible material such as excelsior or scrap lumber would be placed on or around the munitions. The combustible material would be ignited to help initiate burning of the explosive. Before it

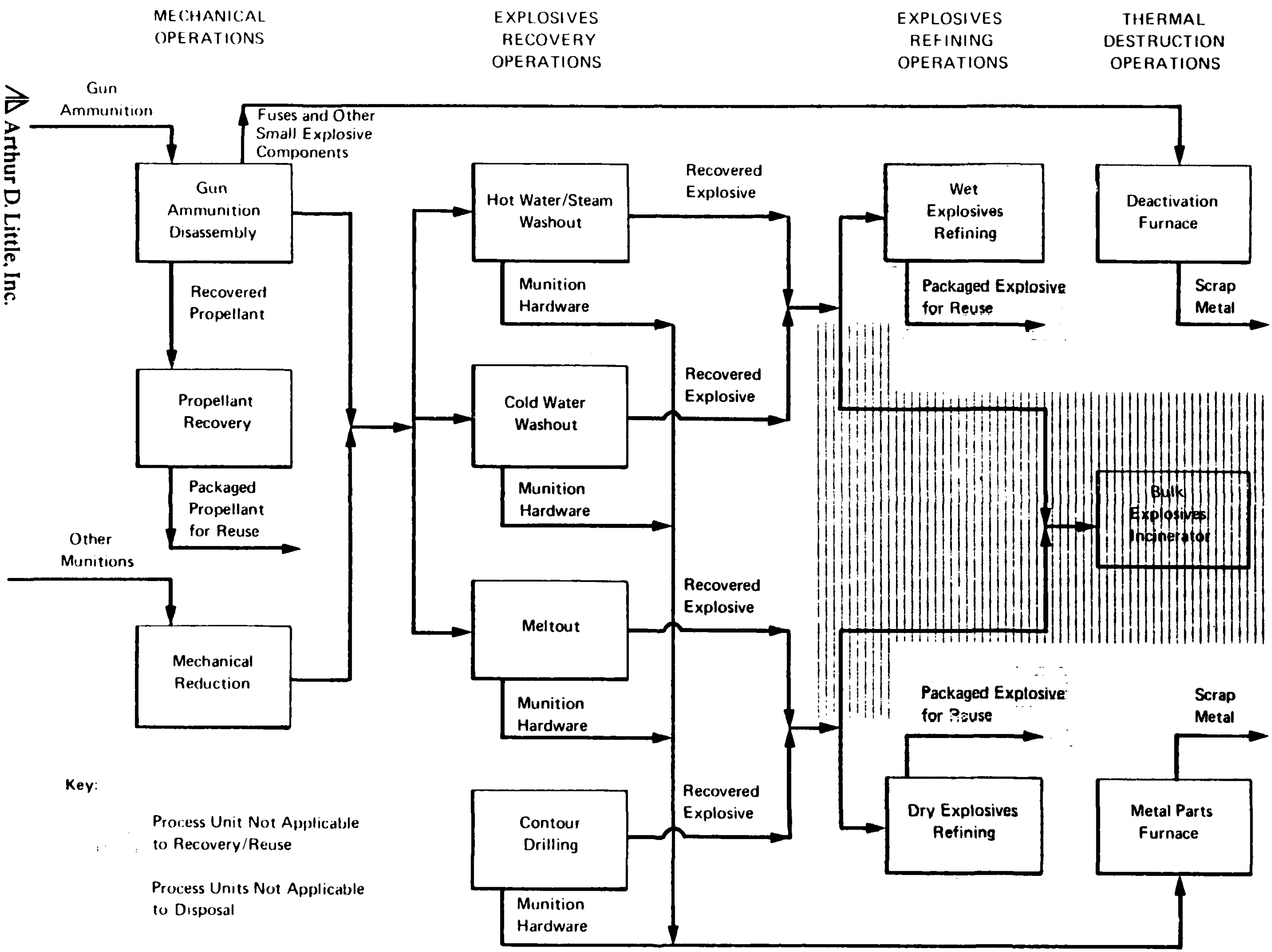

Figure 3-1 DISPOSAL OF OR RESOURCE RECOVERY FROM OBSOLETE AND UNSERVICEABLE MUNITIONS

could be sold as scrap metal or disposed of, the residual munition hardware would be flashed to insure that it contains no residual explosive. (6)

Open detonation, as its name implies, involves detonation of explosives or munitions. It can be conducted at ground surface or in pits. The explosives or munitions would be stacked in intimate contact with demolition blocks or other initiating explosives. Ignition of the initiating charges would cause detonation of the energetic material. The detonation area would subsequently be searched to recover unexploded materials, which would be detonated in place or recovered for treatment in another detonation operation. Metal fragments would also occasionally be recovered from the site using a magnet. (6)

Open detonation facilities vary significantly from installation to installation. In general, they differ in terms of their physical location with respect to ground level (i.e., above ground versus below ground), and subsurface detonation facilities have varying depths below the ground surface. In addition to the physical characteristics of the detonation facility, other factors dictate the amount of explosive that can be destroyed in a single open detonation operation, including: site characteristics that affect blast propagation, meteorological conditions, proximity to population centers, and the history of public dissatisfaction with detonation operations. These factors contribute to vast differences in site-specific detonation capabilities. For example, Anniston Army Depot (ANAD) has a limited above ground open detonation capability of 15 pounds of explosive per campaign, while Sierra Army Depot (SIAD) can detonate up to 10,000 pounds in its above ground facility. Similarly, at the Seneca Army Depot (SEAD) underground detonation facility only 50 pounds of explosive can be detonated at a time, while at Tooele Army Depot (TEAD) 10,000 pounds can be detonated in one campaign using its underground detonation facility. (6)

3.3 RESOURCE RECOVERY/CONTROLLED DISPOSAL

3.3.1 Mechanical Processing Operations

Mechanical processing of many ammunition items is required prior to the removal of main charge explosives for recovery/reuse or disposal. Three types of mechanical operations are typically involved:

- ammunition disassembly;
- propellant handling; and
- mechanical reduction.

A description of each operation follows. These descriptions are based on the operations used at the Hawthorne Army Ammunition Plant (HWAAP) demilitarization facility, as described in Reference 7.

3.3.1.1 Ammunition Disassembly

The ammunition disassembly system is used primarily to disassemble gun ammunition. A typical system could consist of up to two groups of equipment: 1) gun ammunition breakdown and defuzing equipment; and 2) large item defuzing equipment. The configuration of the ammunition items to be demilitarized dictates the appropriate process.

Gun ammunition breakdown and defuzing entails three major processes: 1) breakdown; 2) depriming; and 3) defuzing. Each process is usually accomplished in a separate explosion containment cubicle with remote controlled equipment. Transfer operations into, within and out of the cubicles may be accomplished manually or by mechanical means. In one illustrative mechanical system, ammunition items would be manually placed (with the help of appropriate mechanical lifting devices) on a conveyor that is used to transfer the items to the explosion containment cubicle. Fixed rounds would be transferred to a pull apart machine which engages the cartridge case flange in a flange holder; a clamp which engages the projectile would subsequently pull the projectile out of the cartridge case. The cartridge case would then be transferred to a cartridge case cutting machine that is used to cut off an inert, upper portion of the cartridge case, which is subsequently directed to a deactivation furnace. The remaining portion of the cartridge would be transferred to a case dumper machine. Cartridge cases from semi-fixed rounds would bypass the preceding operations and would be directly transferred to the same case dumper machine. This device engages the cartridge case, extracts nonpropellant materials (i.e., the wad, distance piece, lead foil, etc.), and rotates the case to a vertical, base-up orientation, thereby dumping the propellant into a hopper. The emptied cartridge cases would be removed from the case dumper and transferred to the depriming unit.

Depriming is typically achieved in a separate explosion containment cubicle by remote control. Each cartridge case would be transferred separately (mechanically or manually) to the deprimer, where a punch rod would shear through the flange of the primer (if press-type primers are being removed) or through the base of the cartridge case (if screw type primers are being removed) and continue until the end of the punch passes completely through the cartridge case base. The primer would fall into the cartridge case where it would be left until it is removed manually after the case is transferred out of the depriming cell.

Projectiles released from the pull-apart machine (or projectiles of semi-fixed or separated rounds and rocket warheads) would subsequently be transferred to a defuzing operation. Defuzers can simultaneously loosen and unscrew both nose and base fuzes. When thread disengagement is completed, the fuzes would be pulled away from the projectile body and deposited in fuze containers. Fuzes would, subsequently be destroyed in deactivation furnaces. The projectile bodies would usually be loaded into containers prior to further processing.

Defuzing of large items is usually accomplished with a standard major caliber defuzer in large explosion containment cubicles. A portable vacuum cleaner may be used to remove particles of explosives from the fuze and base cavities of projectiles after removal of the fuzes and base plugs. The large munition items would typically be moved using cranes and hoists.

3.3.1.2 Propellant Handling System

The propellant handling system has three functions: 1) collection of propellant from the breakdown of gun ammunition, 2) transfer of propellant to an accumulation source, and 3) preparation of propellant for subsequent action. Propellant dumped from cartridge cases would be collected in a hopper (equipped with chutes/screens to preclude discharge of nonpropellant materials) and fed by a vibrating screen feeder to a belt conveyor. The conveyor would transfer the powder from the explosion containment cell of the gun ammunition demilitarization system to a storage hopper.

Propellant would typically be containerized. To accomplish this, it would be fed from the storage hopper through a vibrating feeder into a weigh hopper. An empty container would be placed beneath the filling leg to receive propellant from the weigh hopper. The filled container would be moved to another location where it would be sealed and labelled. The container would then be delivered to a loading dock for transport to its destination where it would be reused or destroyed.

Dust control equipment would be provided to recover propellant dust generated during transfer operations (i.e., at the vacuum exhaust of the storage hopper). Vacuum cleanup equipment would also be used to control fugitive propellant emissions. In each system, particulates would commonly be removed from the air stream by way of a cyclone collector, followed by either a wet scrubber or a fabric filter.

3.3.1.3 Mechanical Reduction System

The mechanical reduction system is used to prepare a wide variety of ammunition items for subsequent explosives removal and/or decontamination processes. The system is designed to access the interior of moderate and large munition items to provide for subsequent explosive-charge removal or for viewing/venting.

Mechanical reduction (i.e., sawing) of large items is typically performed in large explosion containment cubicles. Ammunition items would be moved into and within the cubicles by means of cranes and hoists. After clamping the item in place on the saw table, the table would be positioned near the saw. Water coolant supply and discharge lines would also be positioned near the area to be cut. The actual sawing operation would be accomplished by remote control. Chips of metal and explosives (i.e., the swarf) generated by the cutting action, together with the water coolant, would be directed to a filter unit to separate particles from the coolant which would ultimately be recycled to the sawing operation. Contaminated material collected by the filter would be destroyed in a deactivation furnace or during a flashing operation.

A band saw would be used to saw smaller sized items into two sections. Items to be sawed would be manually placed on a tooling carrier, and a mechanical assist device would be available to facilitate positioning of heavy items. Once the tooling carrier was loaded, it would be transferred to an explosion containment cubicle by a powered roller conveyor. Upon reaching the saw, the carrier would be locked into the bed, and the band saw would be engaged. Water would be used to cool the item during sawing and to entrain the swarf material. The cooling water would be collected, filtered to remove swarf, and recycled. When the sawing operation was completed, the carrier would be conveyed out of the cubicle. The items would be manually wiped to remove explosive or metallic debris, and the items that contain substantial amounts of explosives would be covered with plastic for protection until meltout, steamout, washout or contour drilling of explosives can be accomplished. Small end pieces would be decontaminated using a deactivation furnace.

Hole cutting equipment could be used for cutting vent or viewing holes in large ammunition hardware from which explosives have been removed by washout, steamout, meltout or contour drilling. If incorporated in the demilitarization process, this may promote more effective decontamination of these metal parts. Using a jib crane, the item to be processed would be transferred to a carrier and clamped into position. The item would be conveyed into an explosion containment area and directed to the hole cutting equipment. A typical hole cutting machine consists of six hydraulically powered, horizontal axis drill heads equipped with six hole cutting saws; there are also six wall mounted, hydraulically actuated back stops to counter force applied by the drilling head. Cooling water would be applied during the sawing operation; it would also serve as means of collecting swarf. The swarf would be separated from the cooling water by filtration and would be disposed of in the deactivation or metal parts furnaces; filtered cooling water would be recycled. When hole sawing is complete, the item would be removed from the explosion containment cubicle by the same conveying apparatus.

Punching/shearing equipment is used to expose the explosive charge of relatively small ammunition items which are not candidates for recovery/reuse, but rather are to be disposed of by incineration. The operator would place the items to be processed on a tooling carrier which would be transferred to the proper position in the punching/shearing machine, a hydraulic press equipped with punching tools with strippers. Once the ammunition items are punched/sheared, the tooling carrier would be transferred out of the cell.

3.3.2 Explosive Recovery Operations

Main charge explosives must be recovered from munition hardware prior to their disposal or reuse. This is usually accomplished by:

- washout/steamout processes;
- the meltout process; or
- contour drilling.

The technology used for recovering high explosives by these processes is not materially dependent upon the final disposition of the recovered explosive (i.e., whether it is to be disposed of or recovered). The following technology descriptions are based on the HWAAP systems. (7)

3.3.2.1 Washout/Steamout Processes

Washout and steamout processes are commonly used to remove main charge explosives from moderate to large sized munition items in preparation for disposal or reuse. There are two such processes: hot water washout/steamout and cold water washout.

The objective of hot water washout/steamout systems is to recover case-loaded main charge explosives from ammunition items. The process is based on: 1) removing explosives by impinging hot water and/or steam on the explosives; 2) draining the molten or slurried explosives; 3) separating water from the explosives; 4) preparing explosives for subsequent activities; and 5) preparing munition hardware for decontamination.

Large items that arrive at the hot water washout/steamout system would each be fitted with an adaptor at the hardware opening. They would then be lifted with a hoist or crane and positioned on holding/positioning stands. A tubular lance would be inserted through the adaptor to admit hot water and/or steam to the items. As the processing proceeds, molten or slurried explosive would be drained from an outlet in the adaptor, and the lance would be advanced into the cavity as the explosive is drained. Due to the wide range of munition sizes, a variety of lance lengths and adaptors are required.

Smaller munitions are processed using a hot water washout/steamout turntable. The process involves three steps: 1) loading munitions onto the turntable; 2) hot water washout/steamout; and 3) removing the hardware from the turntable. The turntable has three stations; at each station one process step is conducted.

The molten or slurried explosives collected in the hot water washout/steamout process would be drained by gravity to a steam jacketed, insulated kettle. Water would be separated from the explosives by gravity. If the explosives are nonreusable, they would be directed to the kernelling machine prior to incineration. If the explosives are to be reused, they would be directed to a belt flaker. The flaker is a horizontal flat belt conveyor upon which the molten explosives would be discharged. Cooling water would be sprayed on the underside of the conveyor belt, allowing the explosive to cool and solidify. The solid explosive would be broken into flakes by a breaker roll mounted over the head pulley of the conveyor; it would then be weighed and packaged.

Once the hot water washout/steamout operation is completed, the munition hardware could be transferred directly to a thermal detoxification unit or to autoclaves. The autoclaves are used to melt residual explosives and hot-melt liner material that is contaminated with explosives. This is accomplished by direct contact with low pressure steam. The explosive, liner, steam condensate and cooling water (used to cool the items after residue meltout) from the autoclave would be drained by gravity into a kernelling machine wherein the molten explosives and liner material would be agglomerated into solidified "kernels." In one system the materials solidify and agglomerate on contact with water, and a paddle wheel moves the solid particles above the water surface to a chute and finally to a container. These solids are typically disposed of by incineration. Water is treated and recycled to the process.

A fume collector would be used to clean air drawn from the hot water washout/steamout system of particles and explosive vapors. A fume collection system would typically consist of collector hoods, a wet scrubber and an induced draft blower.

Hot water washout/steamout systems are commonly applied to cast explosives that melt readily. However, some press-loaded explosives do not melt readily and do not lend themselves to removal from munition hardware by such processes. One such explosive is Composition A-3. Hydraulic processes have been used to remove this explosive from ammunition hardware. The cold water washout system is designed to hydraulically remove the entire charge of press-loaded explosives from gun ammunition projectiles. This is accomplished by directing a stream of high pressure, cold water at the explosive from a nozzle on a movable lance.

A washout turntable is used to hold projectiles during the cold water washout operation. One such table rotates through four stations, such that four different operations occur simultaneously. Two projectiles would be manually placed on the turntable at the first station. The table would then rotate and the projectiles would move to the second station where high pressure (up to 10,000 psig) cold water would be impinged on the explosive via lances; this is "rough boring" which removes the major portion of the explosives from the munition hardware. "Finish boring" would occur at the third station, also through the use of high pressure water introduced to the munitions via lances. The emptied projectiles would be manually removed from the table at the fourth station. The water/explosives slurry resulting from the washout operation would be directed to an incinerator, if it were not to be reused, or to a solid/liquid separator, if it were to be recovered.

Wastewater from the various demilitarization operations would typically be treated in a single facility. It would be collected in sumps and/or pumped directly to holding tanks. Explosive components and other solid debris would usually be separated using a clarifier. Water would be discharged from the clarifier to a holding tank and the filtered in multimedia (e.g., sand, rock and coal chips) and activated carbon filters. Treated water would be recycled to the demilitarization operations. Clarifier underflow and spent carbon would be incinerated.

3.3.2.2 Meltout Process

In some cases it is desirable to remove main charge explosives from munition hardware without bringing steam or water into contact with the explosives. Explosives with relatively low melting points and low viscosities upon melting (e.g., TNT and Compositions B and B4) are candidates for such operations, since meltout processes consume relatively small amounts of energy for such materials. These processes also recover explosives with low moisture pickup, thereby enhancing reusability or salability of the material.

Autoclaves are the backbone of the explosives meltout system. Ammunition items would be manually loaded onto autoclave fixtures which serve multiple functions: they hold the ammunition items secure during transport to and within the autoclaves; they isolate steam from the explosives; and they direct molten explosives to the appropriate discharge location. The fixtures would typically be mounted on fixture loading turntables that are provided to facilitate loading and unloading operations. A crane would commonly be used to transfer loaded fixtures to the autoclaves.

Within the autoclaves, steam would be applied to the exterior of ammunition items; the melted explosive would be drained and kept from contacting the steam. The autoclaves are commonly pivotable from a vertical orientation (for loading/unloading) to a 45 degree off-vertical orientation (during the melting operation). Inclination of the chamber results in improved heat transfer and drainage of molten explosives from munition items. A steam-jacketted trough would receive explosives and keep them in the molten state.

The explosives would be transferred by gravity through steam-jacketted drain piping to melt kettles. These vessels may be steam jacketed or contain heating elements to keep the contained explosives in the molten state.

The molten explosives would be discharged to a belt flaker, which is essentially a horizontal, flat belt conveyor. Cooling water would be sprayed on the underside of the stainless steel belt, upon which the molten explosive would be cooled and solidified. A breaker roll would be mounted over the head pulley of the belt conveyor to cause the solidified brittle strips of explosive to break into flakes. Flaked explosives would be directed to a vibratory feeder that transfers them to a container placed on a scale.

A fume control hood would be required over the belt flaker. Fume collection equipment would also be required for the explosives meltout system, including ventilation hoods, appropriate ductwork, dampers and a wet scrubber.

3.3.2.3 Contour Drilling

In contour drilling, a cutting tool mounted on the end of a boring bar is directed into the munition cavity through an opening while the munition or bar is rotated. The cutting tool moves radially and axially into the munition, thereby cutting and removing the main charge explosive. The cutting tool is capable of lateral movement and follows the interior contour of the munition; thus, contour drilling is capable of removing larger quantities of explosives from munitions than other drilling processes that do not incorporate lateral movement (e.g., a boring bar or a drill). However, even contour drilling can not remove the entire main explosive charge. For this reason, it is necessary to incorporate a secondary explosives removal process prior to thermal detoxification of the munition's metal parts in order to avert potential detonation hazards; this can be accomplished by meltout or washout processes. It must be noted that, to date, this requirement has precluded the use of contour drilling in production demilitarization operations.

Munitions to be contour drilled would be conveyed into an explosion containment cubicle. Each munition would be placed on a contour drilling lathe by the operator or an industrial robot. Multiple lathes may be used to meet production requirements. Upon initiation of contour drilling, explosive particles removed from munitions would be collected by a pneumatic vacuum collection system and transported to the explosives storage area. Cyclone separators would be used as primary separators to remove the explosives from the air stream and to transfer them to a receiving hopper. A wet scrubber or a fabric filter would be used to clean residual explosive particles from the air stream. Explosives would be fed from the receiving hopper into containers placed on the roller conveyor. The appropriate fill quantity would be determined by weight.

3.3.3 Recovered Explosives Refining Operations

Explosives recovered from obsolete and unserviceable military materiel must meet Army specifications in order to be reused in new munitions. The pertinent specifications for recovered TNT and Composition B are listed in Tables 3-1 and 3-2, respectively, along with chemical analysis results for these recovered explosives. Examination of these tables indicates a need for refining recovered explosives prior to their reuse. In particular, a need exists to reduce the material's moisture and sodium contents. Additionally, the physical form of the material must be consistent with the Army's needs.

Explosives refining operations could be incorporated in the recovery process, or, alternatively, they could be conducted at a central location. They typically involve removal of metal particles and moisture from the explosive, as well as adjustment of the material's particle size distribution. Moisture contents of recovered explosives are expected to vary depending on the recovery method employed. In general, processes that allow intimate contact of water or steam with the explosive (e.g., washout or steamout processes) would be expected to yield a product with a higher moisture content than processes that preclude contact of explosives and water (e.g., meltout or contour drilling). Thus, the refining requirements for such materials are expected to differ. For the purposes of this study, two explosives

TABLE 3-1

CHEMICAL ANALYSIS DATA FOR RECOVERED TNT FROM OBSOLETE AND UNSERVICEABLE MUNITIONS

	Military Specifications	Steamout Recovery/ Vacuum Refining			Meltout Recovery/ No Refining			Hot Water Washout/ Not Known
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1
Moisture Content, %	0.10 Maximum	0.29	0.19	0.24	0.40	1.2	0.76	0.04
Solidification Point, °C	80.2 Minimum	80.2	80.2	78.8	77.8	77.2	77.8	80.1
Acidity, %	0.005 Maximum	0.003	0.002	0.003	0.01	0.009	0.01	0.002
Insoluble Matter, %	0.05 Maximum	0.03	0.01	0.02	0.03	0.02	0.02	0.03
Sodium, %	0.001 Maximum	0.154	0.012	0.011	0.02	0.164	0.194	_0.001

Sources: Explosives Analysis - U.S. Army Armament Research and Development Command
Military Specification - Reference 8

TABLE 3-2

CHEMICAL ANALYSIS DATA FOR RECOVERED COMPOSITION B FROM OBSOLETE AND UNSERVICEABLE MUNITIONS

	Military Specifications		Recovered
	Type I	Type II	Explosive
RDX Content, %	59.5 ± 2.0	59.5 ± 2.0	56.57
TNT Content, %	39.5 ± 2.3	39.5 ± 2.3	42.62
Wax Content, %	1.0 ± 0.3	1.0 ± 0.3	0.81
Moisture Content, %	0.20 max.	0.20 max.	0.04
Bulk Density, gm/cc	--	0.90 min.	0.92
Insoluble Particles Retained on USS #60 Sieve, %	5 max.	5 max.	0.0
Viscosity, Efflux Seconds Max.	Grade A - 7.0 Grade B - 17.0	-- --	4.8
Granulation			
• Passing USS #10 Sieve, %	--	100 min.	1.5
• Passing USS #200 Sieve, %	--	1.0 max.	0.0

Sources: Explosives Analysis - U.S. Army Armament Research and Development Command
Military Specification - Reference 9

refining options were considered: a "wet" explosives refining system for explosives recovered by washout or steamout processes and a "dry" explosives refining system that would be used to refine explosives recovered by other methods.

In a centralized refining plant "wet" explosives refining would be initiated with the receipt of packaged, recovered explosives. The explosives would be removed from their packaging and placed on an inspection table where they would be visually inspected. Foreign matter, if identified, would be removed. The explosives would proceed to a screening and magnetic separation unit to further reduce their foreign matter content. The explosives would then be subject to grinding for size reduction. The ground explosives would be screened to remove oversized particles (which would be recycled to the grinder). They would also be directed to a magnetic separator for removal of metallic impurities. The explosives would then be washed with water and dried using a rotary filter and a belt drier. The water recovered from these units would be directed to a wastewater treatment system. The explosives would subsequently be melted and subjected to vacuum treatment to remove residual moisture. At this point they would be blended, if necessary, in order to produce the desired product composition. The molten product would be solidified and sized using a belt flaker or a grainer. It may once again be screened and subjected to magnetic separation prior to being weighed and packaged. (10)

The "dry" explosives refining system differs from the "wet" explosives refining system in that it does not incorporate explosives washing units. The explosives would be subjected to the same initial unit operations (i.e., inspection, screening, magnetic separation, size reduction and secondary screening/magnetic separation). At this point, however, the explosive would be melted and treated with vacuum to remove the small amount of moisture that it may have picked up during storage. Blending equipment would be provided in case this operation is required (e.g., to adjust the TNT/RDX ratio of Composition B). The molten explosive would then be solidified and sized using a belt flaker or a grainer. It would be screened and directed to a magnetic separator prior to being weighed and packaged. (10)

It is important to note that the refining process descriptions provided in this report are conceptual in nature. The process designs reflect the best judgements of the U.S. Army ARDC, and the systems are anticipated to perform adequately. However, at present there are no available data to support any performance claims regarding these processes.

3.3.4 Thermal Destruction Operations

3.3.4.1 Metal Parts Inerting and Small Items Deactivation

Metallic constituents of ammunition items must be rendered inert before being disposed of or sold as scrap. This can be accomplished by deactivation (i.e., initiating the contained energetic material under controlled conditions while it is in the item). Inerting, a second method, is discussed later in this section. Deactivation is generally limited to disposal of ammunition components (e.g., fuzes, etc.) and small-to-moderate sized ammunition items from which explosives can not be recovered economically. It involves heating the items to a temperature at which the contained energetic material decomposes, burns or detonates, with provisions for containing all fragments generated by detonation.

Items would be delivered to the deactivation furnace system in appropriate containers and would be transferred to a conveyor using a mechanical assist device. The operator would manually remove the container cover and move the container into position for dumping. A rotary dumper, operated from a remote location, may be used to dump the contents of the container into a stationary feed chute that directs ammunition items onto vibratory dumper conveyors. These conveyors have timer-controlled discharge gates that smooth out the flow of material and prevent excessively high instantaneous flow rates. The dumper conveyors discharge to furnace feed conveyors that deliver the ammunition items to the deactivation furnace, a rotary incinerator.

Some deactivation furnaces have provisions for separation of lead from other scrap metals; molten lead from the furnace would be collected in a heated trough, transferred to a quench tank, and moved through the tank on a cooling conveyor. Lead would subsequently be removed from the quench tank by a conveyor and discharged to containers or transport vehicles. Other deactivated scrap metal would be conveyed from the furnace by vibratory feeders and discharged to a quench tank. A conveyor moves the metal through the water to effect cooling. The cooled scrap metal would be fed to a magnetic separator. Magnetic materials and nonmagnetic materials would be separated and discharged to separate containers or transport vehicles.

Air pollution control systems are required for deactivation furnaces. A typical system would consist of a cyclone separator, a flame arrestor, a baghouse and an induced draft fan. Stack gases would be vented to the atmosphere from a vertical exhaust stack.

As was discussed earlier in this section, it is necessary to render metal components of demilitarized munitions inert prior to their disposal or sale as scrap metal. Medium to large sized munitions contain sufficiently large quantities of energetic materials to preclude their demilitarization by deactivation. In such cases, energetic materials would be removed from the munition hardware, and the remaining metallic hardware would be rendered inert by thermal treatment, a process whereby the item is heated to a temperature at which any residual energetic material on or within the items decomposes or burns. Inerting would be achieved through the use of a metal parts furnace.

A typical metal parts furnace is a tray-type flashing furnace. Items to be treated would be loaded into appropriate trays prior to being fed to the furnace. The trays consist of two components: a standardized skid and grids designed to accommodate a particular size or type of ammunition item hardware and which fit into the skids. The tray/grid assembly and loading operations require numerous roller conveyors and transfer devices (for movement of trays), as well as a load station tilt table and mechanical assist device to facilitate tray loading.

The loaded trays would subsequently be fed one at a time to a refractory-lined heat treating furnace. The trays could be moved through the furnace on a walking beam conveyor. Once a tray reaches the end of the furnace it would be conveyed away from the incinerator and its contents would be dumped into a waiting transfer mechanism. The tray would then be conveyed to a cooling station. The tray would finally be conveyed to the grid changing station.

Combustion gases from the furnace would be cooled, and some heat may be recovered thereby reducing energy requirements. The cooled exhaust gases would be passed through a fabric filter to remove particulate matter prior to discharge of these gases to the atmosphere through a stack.

3.3.4.2 Thermal Destruction of Bulk Explosives

A bulk explosives disposal system is designed to dispose of nonreusable or nonsalable propellants and bursting charge explosives, as well as explosives-contaminated wastes and sludges. The system is based on rotary kiln incineration of explosives and propellants.

Materials to be incinerated would be delivered to the bulk explosives disposal system as solids or slurries and discharged to a hopper mounted over the receiving end of a vibratory conveyor. The vibratory feeder would be used to transfer material from the hopper to a grinder. The feeder maintains a steady, regulated flow of material to the grinder and moves the energetic material through a metal detector to ensure that no metal items are fed to the grinder. Water would be sprayed into the feed hopper to flush energetic material through the grinder and to reduce the hazard potential of grinding. Following the grinding, the energetic materials would be slurried in water in preparation for incineration. The slurrying vessel would be equipped with agitators to ensure that the solids remain in suspension. The explosives/water slurry is commonly prepared on a batchwise basis.

The explosives/water slurry would be transferred to feed tanks prior to being charged to a refractory-lined rotating incinerator. The combustion products would typically be directed to an afterburner. Hot gases from the afterburner would be discharged to a particulate control device, and subsequently to the atmosphere through a stack.

SECTION 4

ECONOMIC ANALYSIS

4.1 INTRODUCTION

This economic analysis of waste management options for obsolete and unserviceable conventional ammunition addresses two fundamental issues:

- USATHAMA has no comprehensive capital and operating cost data base for resource recovery from or disposal of obsolete and unserviceable conventional ammunition; and

- The economic attractiveness of recovering explosives and propellants from obsolete and unserviceable munitions must be established to support management decisions regarding future resource expenditures for research and development of these technologies.

Consequently, Section 4 of this report is made up of two major elements. Sections 4.2 and 4.3 present the generic capital and operating cost data bases for open detonation and resource recovery/controlled disposal, respectively. These data form the basis for the case study (i.e., the economic analysis) of the relative economic feasibility of the waste management options of interest that comprises the remainder of this section; the results of the case study are presented in Section 4.4. This approach has two advantages:

- The generic cost estimates presented in Sections 4.2 and 4.3 can be used not only for this specific economic analysis, but will also serve as a general cost database for resource recovery from and disposal of obsolete and unserviceable conventional ammunitions.

- The case study presented in Section 4.4 will address a specific fraction of the obsolete and unserviceable munitions stockpile and will take into account site-specific stockpile distributions as well as the availability of existing resource recovery/disposal facilities; thus, this economic analysis will address actual conditions rather than abstract concepts.

For the purposes of this study, a segment of the inventory of obsolete and unserviceable conventional ammunition was selected for consideration. Five representative munitions were selected for the following reasons:

- Since TNT and Composition B have high potentials for reuse, only munitions that contain these explosives were considered for this analysis.

- Because a wide range of explosives recovery processes were to be considered, only munitions that are amenable to the use of all processes were selected.

- Only munitions that would yield large quantities of explosives were considered, since those munitions are prime candidates for resource recovery.

The selected items comprise twelve percent of the total tonnage of obsolete and unserviceable conventional ammunition, and are stored at eight army installations, as shown in Table 4-1. It must be noted that this is a "representative" selection of munitions which in no way should be construed as a total listing of munitions that are candidates for resource recovery.

4.2 OPEN DETONATION COST ESTIMATES

The costs associated with open detonation of the selected munitions include only operational costs. Detonation facilities are in place at all of the relevant Army installations, and, consequently, no new capital investment is necessary to implement this thermal treatment operation. Thus, for the purpose of this analysis, the capital costs of detonation facilities are assumed to be sunk costs. It must be noted that the regulatory climate surrounding open field burning and detonation is currently in a transitional phase. Within the next few years it is possible that these practices may be more strictly regulated or abolished altogether. If changes in environmental laws result in implementation of standards for open burning/open detonation facilities, new capital expenditures would likely be required for the upgrading of existing facilities or the construction of new ones. Since the anticipated form of such standards can not currently be ascertained, the magnitude of such capital expenditures cannot be estimated at this time.

Unit operating costs for open detonation of the selected munitions were compiled (13,14), as shown in Table 4-2. Since the case study pertains to a representative processing rate of 250,000 lb/yr of explosives at each installation, the annual costs of detonating this quantity of explosives in the munitions of interest were also calculated. (Actual explosives processing rates are dependent on the types of munitions that comprise the site-specific inventories. While site-specific processing rates could be higher or lower than the representative value selected for this study, the selected value represents an overall typical value.) The unit costs include all associated operating costs including labor, materials and overhead. They were developed on the basis of actual operating data and reflect September 1985 economic conditions.

4.3 RESOURCE RECOVERY/CONTROLLED DISPOSAL COST ESTIMATES

Section 3.3 illustrates that the recovery of explosives from obsolete and unserviceable munitions involves a number of operations that are also used in disposal of the same munitions. As such, a modular approach was adopted in Section 3.3 for describing the relevant processing units. Similarly, a modular approach to cost estimating has been adopted. The resource recovery and disposal systems considered in this study were divided into 11 process modules:

TABLE 4-1

MUNITIONS SELECTED FOR CONSIDERATION IN THE ECONOMIC ANALYSIS

Explosive	Installation[a]	Munition	Munition Quantity	Explosive Quantity (lb/item)	Explosive Quantity (lb)
TNT	CAAA	Bomb, Semi-Armor Piercing, M59A1	816	315	257,040
	HWAAP	Depth Charge, MK-9, Mod 1	1,217	190	231,230
	MAAP	Warhead, Rocket, 5-inch, MK-10	NA	15	NA
		Warhead, Rocket, 5-inch, MK-12	NA	16	NA
	NADA	Cartridge, 90-mm, M71	89,836	2	179,672
	PUDA	Cartridge, 90-mm, M71	30,034	2	60,068
	SIAD	Cartridge, 90-mm, M71	9,961	2	19,922
			SUBTOTAL TNT IN MUNITIONS		747,932
Comp B	HWAAP	Rocket, HE, 3.5-inch, M28A2	106,051	1.88	199,376
		Warhead, Rocket, HE, 5-inch, MK25-1	14,453	15	216,795
		Warhead, Rocket, HE, 5-inch, MK63-0	514	15	7,710
	MAAP	Rocket, HE, 3.5-inch, M28A2	239,468	1.88	450,200
		Warhead, Rocket, 5-inch, MK-10	184	15	2,760
	NADA	Cartridge, 90-mm, M71	61,606	2	123,212
	PUDA	Cartridge, 90-mm, M71	93,388	2	186,776
		Rocket, HE, 3.5-inch, M28	539,609	1.88	1,014,465
	RRAD	Rocket, HE, 3.5-inch, M28	487,821	1.88	917,103

TABLE 4-1 (continued)

MUNITIONS SELECTED FOR CONSIDERATION IN THE ECONOMIC ANALYSIS

Explosive	Installation[a]	Munition	Munition Quantity	Explosive Quantity (lb/item)	Explosive Quantity (lb)
Comp B	SIAD	Cartridge, 90-mm, M71	24,919	2.0	49,838
		Rocket, HE, 3.5-inch, M28	51,184	1.88	96,226
	TEAD	Rocket, HE, 3.5-inch, M28A2	200,000	1.88	376,000
			SUBTOTAL COMP B IN MUNITIONS		3,640,461

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[a] CAAA = Crane Army Ammunition Activity
HWAAP = Hawthorne Army Ammunition Plant
MAAP = McAlister Army Ammunition Plant
NADA = Navajo Depot Activity
PUDA = Pueblo Depot Activity
RRAD = Red River Army Depot
SIAD = Sierra Army Depot
TEAD = Tooele Army Depot

NA = Not Available

Sources: Munition Quantities - Reference 11
Explosive Quantities - Reference 12

TABLE 4-2

OPERATING COST ESTIMATES FOR OPEN-FIELD DETONATION OF SELECTED OBSOLETE AND UNSERVICEABLE MUNITIONS

Munition	Unit Detonation Cost ($/munition)	Annual Detonation Cost ($ '000/yr)[a]
Bomb, Semi-Armor Piercing	33.00	26.2
Cartridge, 90-mm	2.85	356.3
Depth Charge, MK-9	11.30	14.9
Rocket, 3.5-inch	2.05	272.6
Warhead, Rocket, 5-inch	4.35	72.5

[a] Annual detonation cost is the cost of detonating 250,000 lb/yr of explosives contained in the noted munitions.

Source of Unit Detonation Costs: References 13 and 14

- Gun Ammunition Disassembly System;
- Propellant Handling System;
- 3.5-Inch Rocket Disassembly System;
- Large Items Mechanical Reduction System;
- Hot Water Washout/Steamout System;
- Meltout System;
- Wet Explosives Refining System;
- Dry Explosives Refining System;
- Deactivation Furnace System;
- Metal Parts Decontamination System; and
- Bulk Explosives Incineration System.

Each module (with the exception of the Wet Explosives and Dry Explosives Refining Systems) is designed to handle at least 250,000 lb/yr of explosives. The explosives refining modules are considered to be centralized facilities capable of processing the entire recovered explosives workload of 2,000,000 lb/yr. Some systems are designed to handle a wide range of munitions, and, consequently, they are designed for their most severe operating requirements; as such, these systems could be used to recover or dispose of even larger quantities of explosive depending upon the munition processed. Additionally, the Army has developed standard demilitarization equipment for some applications. Where appropriate, this equipment was considered even though its capacity may be greater than 250,000 lb/yr.

4.3.1 Generic Modular Capital Cost Estimates

Capital cost estimates have been developed for the eleven modules of interest. In developing these estimates, installed equipment costs were obtained from a variety of sources (7,15,16,17), as well as in-house files of the U.S. Army Armament Research and Development Command and Arthur D. Little, Inc. Total capital investment requirements were developed using a factored cost estimating approach. The relevant factors for direct capital costs are noted below:

- Equipment Costs were obtained from a variety of sources. The installation labor cost was assumed to be 25 percent of the purchased equipment cost.

- Piping Costs (including installation costs) for solids handling systems were assumed to be 15 percent of the purchased equipment cost; these costs were estimated to be 30 percent of the purchased equipment costs for operational units that handle liquids or liquid/solid slurries.

- Electrical Costs (including installation costs) were assumed to be 15 percent of the purchased equipment cost.

- Instrumentation Costs (including installation costs) were assumed to be 20 percent of the purchased equipment cost.

- Spare Parts Costs were assumed to be two percent of the purchased equipment cost.

Indirect capital costs include engineering design and supervision, and contractor's overhead and profit; these were estimated at eight and 15 percent, respectively, of the direct capital cost. The total capital investment also includes a contingency factor that was estimated to be ten percent of the total direct and indirect costs. The factors used in these cost estimates were selected on the basis of practical industry experience.

Generic capital costs for the eleven process modules of interest are presented in Tables 4-3 through 4-13. These cost estimates reflect September 1985 economic conditions (Chemical Engineering Index = 326.1). (18)

4.3.2 Generic Modular Operating Cost Estimates

The operating costs associated with the eleven process modules of interest vary with the type of munition being processed. For the purposes of this study, the generic operating cost estimates pertain to the recovery of 250,000 lb/yr of explosives (with the exception of the refining system estimates). In the case that a particular process module is capable of processing greater than 250,000 lb/yr of explosives, it was assumed that the operating period was limited only to the time required to process that volume of explosives. In the case that a process module could not provide the desired throughput with using a one shift operating basis, two operating shifts were specified. The capacities and availabilities of the various process modules (7,15) were used to estimate the applicable operating period.

Unit cost factors were used to calculate labor, utility and transportation costs; the unit cost factors used for this study are averages typical for Army installations:

- Direct Labor and Fringe Benefits - $15.00/manhour;
- Utilities
  - Process Water - $1.25/1,000 gallons;
  - Steam - $14.00/1,000 pounds;
  - Compressed Air - $0.75/1,000 cubic feet;
  - Fuel Oil - $1.00/gallon; and
  - Electricity - $0.05/kW-hr.
- Transportation - $4,400/truckload

Annual costs for maintenance materials and labor were estimated to be four percent of the module's total fixed investment; these annual costs were prorated to reflect the actual operating period. General and administrative overhead were estimated at 65 percent of the cost of operating labor and maintenance.

Munition-specific operating requirements for labor and utilities had to be established to allow one to estimate munition specific operating costs. Utility consumptions were determined from equipment

TABLE 4-3

GUN AMMUNITION DISASSEMBLY SYSTEM CAPITAL COST ESTIMATE[a]

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Jib Cranes, Receiving Area	3	7.4
Jib Cranes, Input Conveyors	2	45.8
Jib Crane, Discharge Conveyor	1	23.0
Vibrating Screen Feeder	1	8.5
Case Input Conveyor	1	29.4
Projectile Input Conveyor	1	29.4
Robot and Hydraulic Unit, Separation Unit	1	146.9
Pull Apart Machine	1	105.9
Case Cutter and Chute	1	148.9
Propellant Dumper/Wad Remover	1	142.1
Case Transfer	1	92.9
Scale Conveyor	1	33.5
Robot and Hydraulic Unit, Depriming Area	1	140.7
Deprimer	1	124.3
Deprimer Exhaust Fan	1	0.8
Output Conveyor	1	14.3
Projectile Input Car	1	14.3
Projectile Transfer Equipment	1	179.2
Defuzers and Hydraulic Units	2	764.9
Projectile Discharge Car	1	14.3
Fuze Containers	11	22.5
Base Fuze Adapters	400	23.5
SUBTOTAL INSTALLED EQUIPMENT COST		2,112.5
Piping	-	253.5
Electrical	-	253.5
Instrumentation	-	338.0
Spare Parts	-	33.8
TOTAL DIRECT COST		2,991.3
Engineering and Supervision	-	239.3
Contractor's Overhead and Fee	-	448.7
TOTAL DIRECT AND INDIRECT COST		3,679.3
Contingency	-	367.9
TOTAL CAPITAL INVESTMENT		4,047.2

[a] System is capable of processing fixed and separated ammunition ranging in size from 75-mm through 5-inch, inclusive, 2.75 and 5.00-inch airborne-type rocket warheads and the cartridge cases of 6-inch gun ammunition.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-4

PROPELLANT HANDLING SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Propellant Conveyor	1	86.8
Fill Hopper and Discharge Equipment	1	15.0
Propellant Feeder	1	5.7
Weigh Hopper and Discharge Equipment	1	59.4
Platform	1	5.1
Gravity Roller Conveyor	1	4.5
Downender	1	49.2
Vacuum Cleaning Systems	4	232.2
Dust Collection Systems	2	60.1
SUBTOTAL INSTALLED EQUIPMENT COST		518.0
Piping	-	124.3
Electrical	-	62.2
Instrumentation	-	82.9
Spare Parts	-	8.3
TOTAL DIRECT COST		795.7
Engineering and Supervision	-	63.7
Contractor's Overhead and Fee	-	119.4
TOTAL DIRECT AND INDIRECT COST		978.8
Contingency	-	97.9
TOTAL CAPITAL INVESTMENT		1,076.7

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-5

3.5-INCH ROCKET DISASSEMBLY SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Jib Crane, Receiving Area	1	2.5
Jib Crane, Transfer Area	1	23.0
Transfer Car	1	14.3
Robot and Hydraulic Unit	1	112.9
Rocket Disassembly Machine (APE 1215)	1	120.0
Grippers and Chutes	1	33.8
Fuze Containers	11	22.5
SUBTOTAL INSTALLED EQUIPMENT COST		329.0
Piping	-	39.5
Electrical	-	39.5
Instrumentation	-	52.6
Spare Parts	-	5.3
TOTAL DIRECT COST		465.9
Engineering and Supervision	-	37.3
Contractor's Overhead and Fee	-	69.9
TOTAL DIRECT AND INDIRECT COST		573.1
Contingency	-	57.3
TOTAL CAPITAL INVESTMENT		630.4

Source: Arthur D. Little, Inc. Estimates based on References 7 and 15

TABLE 4-6

LARGE ITEMS MECHANICAL REDUCTION SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Overhead Crane, Staging Area	1	71.0
Overhead Crane, Reduction Area	1	67.6
Horizontal Band Saw and Hydraulic Unit	1	358.6
Deep Bed Filter	1	10.5
Exhaust Fan	1	0.8
SUBTOTAL INSTALLED EQUIPMENT COST		508.5
Piping	-	61.0
Electrical	-	61.0
Instrumentation	-	81.4
Spare Parts	-	8.1
TOTAL DIRECT COST		720.0
Engineering and Supervision	-	57.6
Contractor's Overhead and Fee	-	108.0
TOTAL DIRECT AND INDIRECT COST		885.6
Contingency	-	88.6
TOTAL CAPITAL INVESTMENT		974.2

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-7

HOT WATER WASHOUT/STEAMOUT SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Mechanical Assists	2	58.9
Pallet Conveyor	1	12.8
Moderate Sized Items Washout Turntable	1	183.1
Jib Crane	1	4.0
Lifting Bail	1	7.8
Large Items Washout Tables and Accessories	2	419.5
Separator Tank and Agitator	1	74.5
Kernelling Machine and Agitator	1	19.3
Belt Flaker and Chiller	1	122.0
Vibratory Feeder	1	2.6
Scale	1	18.7
Box Conveyor	1	0.7
Water Pump	1	0.4
Water Heater	1	10.8
Fume Collector	1	17.4
Container Conveyor	1	5.5
Load Gate	1	0.6
SUBTOTAL INSTALLED EQUIPMENT COST		958.6
Piping	-	230.1
Electrical	-	115.0
Instrumentation	-	153.4
Spare Parts	-	15.3
SUBTOTAL DIRECT COST	-	1,472.4
Engineering and Supervision	-	117.8
Contractor's Overhead and Fee	-	220.9
SUBTOTAL DIRECT AND INDIRECT COST		1,811.1
Contingency	-	181.1
TOTAL CAPITAL INVESTMENT		1,992.2

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-8

MELTOUT SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Estimate	Quantity	Cost ($ '000)
Mechanical Assist	1	30.9
Autoclave Fixtures	5	143.4
Load Station Turntable	1	9.6
Autoclaves and Drain Troughs	2	204.9
Belt Flaker and Chiller	1	122.0
Vibratory Feeder	1	2.6
Scale	1	18.7
Boxed Explosive Conveyor	1	0.7
SUBTOTAL INSTALLED EQUIPMENT COST		532.8
Piping	-	127.9
Electrical	-	63.9
Instrumentation	-	85.2
Spare Parts	-	8.5
TOTAL DIRECT COST		818.3
Engineering and Supervision	-	65.5
Contractor's Overhead and Fee	-	122.7
TOTAL DIRECT AND INDIRECT COST		1,006.5
Contingency	-	100.7
TOTAL CAPITAL INVESTMENT		1,107.2

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-9

WET EXPLOSIVES REFINING SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Inspection Tables	2	5.1
Vibrating Screens	5	30.9
Magnetic Separators	5	7.7
Explosive Size Reduction Equipment	1	18.5
Explosive Wash Tanks	2	39.1
Rotary Filter	1	72.0
Belt Dryer	1	57.6
Premelt Kettle	1	10.3
Melt Kettles	2	237.7
Blender Kettle	1	27.8
Belt Flaker	1	270.6
Grainer	1	51.5
Scale and Accessories	1	21.9
Packaging Unit	1	52.4
Conveyors	1	60.7
Slurry Pumps	2	16.5
Agitators	3	9.3
SUBTOTAL INSTALLED EQUIPMENT COST		989.6
Piping	-	237.5
Electrical	-	118.8
Instrumentation	-	158.3
Spare Parts	-	15.8
TOTAL DIRECT COST		1,520.0
Engineering and Supervision	-	121.6
Contractor's Overhead and Fee	-	228.0
TOTAL DIRECT AND INDIRECT COST		1,869.6
Contingency	-	187.0
TOTAL CAPITAL INVESTMENT		2,056.6

Source: Equipment Costs - U.S. Army Armament Research and Development Command Estimates; Other Costs - Arthur D. Little, Inc. Estimates

TABLE 4-10

DRY EXPLOSIVES REFINING SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Inspection Tables	2	2.1
Vibratory Screens	5	30.9
Magnetic Separators	5	7.7
Explosive Size Reduction Equipment	1	18.5
Premelt Tanks	2	21.6
Melt Kettle	1	237.7
Belt Flaker and Chiller	1	270.6
Crainer	1	51.5
Scale and Accessories	1	21.9
Packaging Unit	1	52.5
Conveyors	-	30.9
SUBTOTAL INSTALLED EQUIPMENT COST		745.9
Piping	-	179.0
Electrical	-	89.5
Instrumentation	-	119.3
Spare Parts	-	11.9
TOTAL DIRECT COST		1,145.6
Engineering and Supervision	-	91.6
Contractor's Overhead and Fee	-	171.8
TOTAL DIRECT AND INDIRECT COST	-	1,409.0
Contingency	-	140.9
TOTAL CAPITAL INVESTMENT		1,549.9

Source: Equipment Costs - U.S. Army Armament Research and Development Command Estimates; Other Costs - Arthur D. Little, Inc. Estimates

TABLE 4-11

DEACTIVATION FURNACE SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Mechanical Assist	1	4.1
Bridge Crane	1	19.8
Dumper Feed Conveyor	1	0.8
Rotary Dumper	1	19.3
Dumper Conveyor	1	13.4
Furnace Feed Conveyor	1	31.3
Deactivation Furnace (APE 1236)	1	447.1
Lead Collection/Cooling System	1	35.1
Scrap Metal Cooling Conveyor	1	27.7
Magnetic Separator Feeder	1	17.1
Magnetic Separator	1	17.4
Scrap Metal Separation Screen	1	18.7
Decision Chute	1	8.3
Air Pollution Control System (APE 1236E010)	1	152.7
Flame Arrestor	1	1.4
Coolant Water Pump	1	3.6
Induced Draft Fan	1	5.7
SUBTOTAL INSTALLED EQUIPMENT COST		823.5
Piping	-	197.6
Electrical	-	98.8
Instrumentation	-	131.8
Spare Parts	-	13.2
SUBTOTAL DIRECT COSTS		1,264.9
Engineering and Supervision	-	101.2
Contractor's Overhead and Fee	-	189.7
SUBTOTAL DIRECT AND INDIRECT COST		1,555.8
Contingency	-	155.6
TOTAL CAPITAL INVESTMENT		1,711.4

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-12

METAL PARTS DECONTAMINATION SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Jib Crane	1	3.8
Projectile Handling Balancer	2	34.0
Monorail Hoist	1	2.3
Grid Changing Conveyor	1	40.0
Tray Raising Device	1	6.7
Load Station Feed Conveyor	1	8.2
Tray Transfer Device	1	6.7
Load/Transfer Conveyors	2	9.4
Load Station Tilt Tables	2	9.8
Tray Lowering Device	1	7.7
Blast Gate Feed/Transfer Conveyors	1	8.2
Furnace Feed Conveyor	1	45.6
Flashing Furnace	1	956.7
Furnace Discharge Conveyor	1	4.6
Tray Discharge Devices	1	15.3
Tray Dumper	1	24.5
Skip Hoist	1	33.9
Discharge Conveyor	1	4.5
Tray Lowering Device	1	6.7
Tray Accumulation Conveyor	1	86.6
Tray Cooling Station	1	53.4
Tray Transfer/Ram-On Device	1	12.9
Tray Accumulating Conveyor	1	47.1
Tray Transfer Device	1	10.1
Skid-Universal	45	104.6
Grids	130	240.2
Air Pollution Control System	1	152.7
SUBTOTAL INSTALLED EQUIPMENT COST		1,936.2
Piping	-	464.7
Electrical	-	232.3
Instrumentation	-	309.8
Spare Parts	-	31.0
SUBTOTAL DIRECT COST		2,974.0
Engineering and Supervision	-	237.9
Contractor's Overhead and Fee	-	446.1
SUBTOTAL DIRECT AND INDIRECT COST		3,658.0
Contingency	-	365.8
TOTAL CAPITAL INVESTMENT		4,023.8

Source: Arthur D. Little, Inc. Estimates based on References 7 and 16

TABLE 4-13

BULK EXPLOSIVES INCINERATION SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Mechanical Assist	1	7.5
Jib Hoist	1	6.1
Monorail Trolley	2	0.3
Input Conveyor	1	29.2
Scale Conveyor	1	6.1
Scale	1	39.8
Scale Transfer Conveyor	1	5.7
Container Dumper Feed Conveyor	1	26.5
Empty Container Transfer Conveyor	1	9.3
Container Accumulating/Transfer/ Storage Conveyors	1	15.7
Container Dumper	1	53.8
Dump Hopper	1	1.5
Grinder Feed Conveyor	1	18.7
Metal Detector	1	6.3
Grinder	1	194.7
Slurry Tank	1	22.1
Transfer Pump	1	2.9
Feed Tank	1	17.6
Recirculating Pump	1	4.5
Incinerator Feed Pump	2	5.2
Explosive Waste Incinerator (EWI)	1	448.6
Air Ejector and Blower	1	19.8
Wash Tank and Agitators	1	18.7
Containers	78	89.8
Spray Water Pump	1	4.5
Ash Containers	2	1.8
Monorail Trolley	1	0.1
Exhaust Fan	1	9.2
Air Pollution Control System	1	258.1
Fuel Oil Tank	1	38.1
Propane Tank	1	1.0
SUBTOTAL INSTALLED EQUIPMENT COST		1,363.2
Piping	-	327.2
Electrical	-	163.6
Instrumentation	-	218.1
Spare Parts	-	21.8
TOTAL DIRECT COST		2,093.9

TABLE 4-13 (continued)

BULK EXPLOSIVES INCINERATION SYSTEM CAPITAL COST ESTIMATE

Equipment Item/Cost Element	Quantity	Cost ($ '000)
Engineering and Supervision	-	167.5
Contractor's Overhead and Fee	-	314.1
TOTAL DIRECT AND INDIRECT COST		2,575.5
Contingency	-	257.6
TOTAL CAPITAL INVESTMENT		2,833.1

Source: Arthur D. Little, Inc. Estimates based on References 7 and 17

specifications and material balance data. The horsepower ratings of electric powered equipment were used to establish electric power consumption. Material and energy balance data were used to calculate process water, steam and fuel requirements. Estimates of labor requirements were based on process and equipment operating requirements.

Tables 4-14 through 4-26 present the generic operating costs for the eleven process modules of interest. Tables 4-27 through 4-30 summarize the total annual operating costs associated with the processing of 250,000 lb/yr of explosives from the munitions of interest by the following processes:

- explosives are removed from the munitions of interest using a hot water washout/steamout process and are refined for subsequent reuse (Table 4-27);

- explosives are removed from the munitions of interest using a meltout process and are refined for subsequent reuse (Table 4-28);

- explosives are removed from the munitions of interest using a hot water washout/steamout process and are incinerated (Table 4-29);

- explosives are removed from the munitions of interest using a meltout process and are incinerated (Table 4-30).

4.4 CASE STUDY

The case study presented in this section is an economic analysis of three management options for obsolete and unserviceable munitions:

- disposal by open field detonation;

- disposal by controlled thermal methods; and

- recovery of useful resources (explosives) for reuse.

The last two options noted above require that explosives be removed from the munition hardware prior to their incineration (for disposal) or refining (for reuse). A variety of explosives removal process have been developed, although only two (i.e., hot water washout/steamout and meltout) have found extensive use in large scale applications. For the purposes of this study, only these two explosives removal processes were considered in the economic analysis.

The economic analysis will focus on the two major types of costs separately. Section 4.4.1 will focus on the relative capital investment requirements of the five options (open detonation, hot water washout/steamout followed by incineration, meltout followed by incineration, hot water washout/steamout followed by refining and meltout followed by refining) of interest. Recurring or annual operations and maintenance costs will be evaluated in Section 4.4.2.

TABLE 4-14

GUN AMMUNITION DISASSEMBLY SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost ($)	90-mm Cartridge Units Required	90-mm Cartridge Cost ($ '000/yr)	5-inch Rocket Warhead Units Required	5-inch Rocket Warhead Cost ($ '000/yr)
Labor	manhours	15.00	19,600	294.0	3,900	58.5
Utilities						
• Electricity	kW-hr	0.05	215,000	10.8	45,000	2.3
• Water	1,000 gal	1.25	2,715	3.4	545	0.7
• Air	1,000 cf	0.75	9,065	6.8	1,815	1.4
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	109.0	--	21.8
General and Administrative Overhead	65% of Labor and Maintenance	--	--	262.0	--	52.2
	TOTAL OPERATING COST			686.0		136.9

[a] The Gun Ammunition Disassembly System is a multipurpose demilitarization facility capable of processing a wide range of munitions; throughputs vary with munition type. Costs are for the processing of 250,000 lb/yr of explosives from the noted munitions. Operating periods are 175 shifts/yr and 35 shifts/yr for the 90-mm cartridge and the 5.0-inch rocket warhead, respectively, including provisions for process downtime.

[b] Prorated to reflect actual operating periods.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-15

PROPELLANT HANDLING SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	5,600	84.0
Utilities				
• Electricity	kW-hr	0.05	145,000	7.3
• Water	1,000 gal	1.25	84	0.1
• Air	1,000 cf	0.75	3,715	2.8
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	29.0
General and Administrative Overhead	65% of Labor and Maintenance	--	--	73.5
	TOTAL OPERATING COST FOR PROPELLANT TO BE DISPOSED			196.7
Propellant Credit	1,000 lb	(1,860)	625	(1,162.5)
	TOTAL OPERATING COST FOR PROPELLANT TO BE REUSED			(965.8)

[a]The Propellant Handling System is available continuously during Gun Ammunition Disassembly operations, and its operating period is dictated by that system as well; costs pertain to the handling of propellant from 90-mm cartridges for a period of 175 shifts/yr.

[b]Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on References 7 and 19

TABLE 4-16

3.5-INCH ROCKET DISASSEMBLY SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	5,000	75.0
Utilities				
• Electricity	kW-hr	0.05	19,000	1.0
• Air	1,000 cf	0.75	12,000	9.0
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	12.1
General and Administrative Overhead	65% of Labor and Maintenance	--	--	56.6
	TOTAL OPERATING COST			153.7

[a]The standard 3.5-Inch Rocket Disassembly System has a higher munition throughput rate than would be required to recover 250,000 lb/yr of explosives from the 3.5-inch rocket. These cost estimates pertain to the recovery of 250,000 lb/yr of explosives from the 3.5-inch rockets; the disassembly system would be required to operate 125 shifts/yr.

[b]Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 15

TABLE 4-17

LARGE ITEMS MECHANICAL REDUCTION SYSTEM OPERATING COST ESTIMATE[a]

			MK-9 Depth Charge		M59Al Semi-Armor Piercing Bomb	
	Units	Unit Cost ($)	Units Required	Cost ($ '000/yr)	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	2,000	30.0	4,400	66.0
Utilities						
• Electricity	kW-hr	0.05	7,400	0.4	20,700	1.0
• Water	1,000 gal	1.25	285	0.4	800	1.0
• Air	1,000 cf	0.75	4,435	3.3	12,500	9.4
Maintenance (Labor and Material)	4% of Total Fixed Investment[b]	--	--	12.0	--	27.8
General and Administrative Overhead	65% of Labor and Maintenance	--	--	27.3	--	61.0
	TOTAL OPERATING COST			73.4		166.2

[a] The Large Items Mechanical Reduction System is a multipurpose demilitarization unit capable of processing a wide range of munitions; throughputs vary with munition type. Costs are for the processing of 250,000 lb/yr of explosives from the noted munitions. Operating periods are 80 and 185 shifts/yr for the MK-9 depth charge and the M59Al semi-armor piercing bomb, respectively, including provisions for process downtime.

[b] Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-18

HOT WATER WASHOUT/STEAMOUT SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost ($)	90 mm Cartridge Units Required	90 mm Cartridge Cost ($ '000/yr)	3.5-inch Rocket Units Required	3.5-inch Rocket Cost ($ '000/yr)	5-inch Rocket Warhead Units Required	5-inch Rocket Warhead Cost ($ '000/yr)	MK-9 Depth Charge Units Required	MK-9 Depth Charge Cost ($ '000/yr)	M59A1 Semi-Armor Piercing Bomb Units Required	M59A1 Semi-Armor Piercing Bomb Cost ($ '000/yr)
Labor	manhours	15.00	10,100	151.5	9,500	142.5	8,700	130.5	7,100	106.5	6,400	96.0
Utilities												
• Electricity	kW hr	0.05	85,000	4.3	79,000	4.0	72,500	3.6	46,000	2.3	42,000	2.1
• Air	1,000 cf	0.75	48,765	36.6	45,665	34.2	41,800	31.4	17,400	13.1	15,800	11.9
• Water	1,000 gal	1.25	6,920	8.7	6,480	8.1	5,930	7.4	2,965	3.7	2,695	3.4
• Steam	1,000 lb	14.00	2,815	39.4	2,635	36.9	2,410	33.7	380	5.3	350	4.9
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	-	--	96.5	--	90.4	--	82.8	--	67.4	--	61.3
General and Administrative Overhead	65% of Labor and Maintenance	--	--	161.2	--	151.4	--	138.6	--	113.0	-	102.2
	TOTAL OPERATING COST			498.2		467.5		428.0		311.3		281.8

[a] The Hot Water Washout/Steamout System is a multipurpose demilitarization system capable of processing a wide range of munitions; throughputs vary with munition type. Costs are for the processing of 250,000 lb/yr of explosives from the noted munitions. Operating periods are 315, 295, 270, 220, and 200 shifts/yr for the 90-mm cartridge, the 3.5-inch rocket, the 5.0-inch rocket warhead, the Mk-9 depth charge and the M59A1 semi-armor piercing bomb, respectively, including provisions for process downtime.

[b] Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-19

TNT MELTOUT SYSTEM OPERATING COSTS ESTIMATE[a]

	Units	Unit Cost ($)	90-mm Cartridge Units Required	90-mm Cartridge Cost ($ '000/yr)	5-inch Rocket Warhead Units Required	5-inch Rocket Warhead Cost ($ '000/yr)	MK-9 Depth Charge Units Required	MK-9 Depth Charge Cost ($ '000/yr)	M59Al Semi-Armor Piercing Bomb Units Required	M59Al Semi-Armor Piercing Bomb Cost ($ '000/yr)
Labor	manhours	15.00	9,800	147.0	2,200	33.0	2,640	39.6	2,640	39.6
Utilities										
• Electricity	kW-hr	0.05	107,000	5.4	24,000	1.2	29,000	1.5	29,000	1.5
• Water	1,000 gal	1.25	1,415	1.8	320	0.4	345	0.4	345	0.4
• Steam	1,000 lb	14.00	380	5.3	105	1.5	250	3.5	250	3.5
Maintenance (Labor and Material)	4% of Total Fixed Investment[b]	--	--	41.7	--	9.4	--	11.2	--	11.2
General and Administrative Overhead	65% of Labor and Maintenance	--	--	122.7	--	27.6	--	33.0	--	33.0
TOTAL OPERATING COST				323.9		73.1		89.2		89.2

[a]The Meltout System is a multipurpose explosives recovery system capable of processing a wide range of munitions; throughputs vary with munition and explosive type. Costs are for the processing of 250,000 lb/yr of TNT from the noted munitions. Operating periods are 245, 55, 66 and 66 shifts/yr for the 90-mm cartridge, the 5-inch rocket warhead, and the MK-9 depth charge, and the M59Al semi-armor piercing bomb, respectively, including provisions for process downtime.

[b]Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-20

COMPOSITION B MELTOUT SYSTEM OPERATING COSTS ESTIMATE[a]

	Units	Unit Cost ($)	90-mm Cartridge Units Required	90-mm Cartridge Cost ($ '000/yr)	3.5-inch Rocket Units Required	3.5-inch Rocket Cost ($ '000/yr)	5-inch Rocket Warhead Units Required	5-inch Rocket Warhead Cost ($ '000/yr)
Labor	manhours	15.00	15,600	234.0	13,900	208.5	3,400	51.0
Utilities								
• Electricity	kW-hr	0.05	170,000	8.5	150,000	7.5	37,000	1.9
• Water	1,000 gal	1.25	2,035	2.5	1,870	2.3	445	0.6
• Steam	1,000 lb	14.00	695	9.7	535	7.5	150	2.1
Maintenance (Labor and Material)	4% of Total Fixed Investment[b]	--	--	66.4	--	58.9	--	14.5
General and Administrative Overhead	65% of Labor and Maintenance	--	--	195.3	--	173.8	--	42.6
TOTAL OPERATING COST				516.4		458.5		112.7

[a] The Meltout System is a multipurpose explosives recovery system capable of processing a wide range of munitions; throughputs vary with munition and explosive type. Costs are for the processing of 250,000 lb/yr of Composition B from the noted munitions. Operating periods are 390, 346 and 85 shifts/yr for the 90-mm cartridge, the 3.5-inch rocket and the 5-inch rocket warhead, respectively, including provisions for process downtime.

[b] Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-21

WET EXPLOSIVES REFINING SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	13,600	204.0
Utilities				
• Electricity	kW-hr	0.05	144,800	7.2
• Steam	1,000 lb	14.00	7,235	101.3
• Water	1,000 gal	1.25	290	0.4
• Air	1,000 cf	0.75	4,790	3.6
Transportation	truckload	4,400.00	60	264.0
Explosives Credit				
• TNT	1,000 lb	(740.00)	500	(370.0)
• Comp B	1,000 lb	(1,480.00)	1,500	(2,220.0)
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	31.6
General and Administrative Overhead	65% of Labor and Maintenance	--	--	153.1
	TOTAL OPERATING COST			(1,824.8)

[a]Cost estimates pertain to a Centralized Wet Explosives Refining System capable of processing 1.5 million lb Composition B/yr and 0.5 million lb TNT/yr. Operation based on 800 hr/yr processing time.

[b]Prorated to reflect actual operating period.

Sources: Labor, utility and transportation requirements - U.S. Army Armament, Research and Development Command Estimates. Explosives Credits Unit Costs - Reference 19. Other costs - Arthur D. Little, Inc. Estimates.

TABLE 4-22

DRY EXPLOSIVES REFINING SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	9,600	144.0
Utilities				
• Electricity	kW-hr	0.05	85,000	4.3
• Steam	1,000 lb	14.00	3,120	43.7
• Water	1,000 gal	1.25	290	0.4
• Air	1,000 cf	0.75	4,790	3.6
Transportation	truckload	4,400.00	60	264.0
Explosives Credits				
• TNT	1,000 lb	(740.00)	500	(370.0)
• Comp B	1,000 lb	(1,480.00)	1,500	(2,220.0)
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	23.8
General and Administrative Overhead	65% of Labor and Maintenance	--	--	109.1
	TOTAL OPERATING COST			(1,997.1)

[a]Cost estimate pertain to a Centralized Dry Explosives Refining System capable of processing 1.5 million lb Composition B/yr and 0.5 million lb TNT/yr. Operation based on 800 hr/yr processing time.

[b]Prorated to reflect actual operating period.

Sources: Labor, utility and transportation requirements - U.S. Army Armament, Research and Development Command Estimates. Explosives Credits Unit Costs - Reference 19. Other costs - Arthur D. Little, Inc. Estimates.

TABLE 4-23

DEACTIVATION FURNACE SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost ($)	90-mm Cartridge Units Required	90-mm Cartridge Cost ($ '000/yr)	3.5-inch Rocket Units Required	3.5-inch Rocket Cost ($ '000/yr)	5-inch Rocket Warhead Units Required	5-inch Rocket Warhead Cost ($ '000/yr)
Labor	manhours	15.00	700	10.5	6,900	103.5	3,500	52.5
Utilities								
• Electricity	kW·hr	0.05	5,900	0.3	57,600	2.9	29,400	1.5
• Water	1,000 gal	1.25	200	0.3	2,000	2.5	1,025	1.3
• Air	1,000 cf	0.75	100	0.1	1,000	0.8	510	0.4
• Fuel Oil	gal	1.00	2,600	2.6	25,800	25.8	13,200	13.2
Metal Recovery	1,000 lb	(20.00)	188	(3.8)	532	(10.6)	88	(1.8)
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	5.8	--	56.6	--	28.9
General and Administrative Overhead	65% of Labor and Maintenance	--	--	10.6	--	104.1	--	52.9
	TOTAL OPERATING COST			26.4		285.6		148.9

[a] The Deactivation Furnace System is capable of destroying the small energetic components of a wide range of munitions; throughputs vary with munition component. Costs are for destruction of components of the noted munitions from which 250,000 lb/yr of explosives were processed. Operating periods are 22, 215, and 110 shifts/yr for the destruction of 90-mm cartridge, fuzes and primers; 3.5-inch rocket, fuzes and rocket motors; and 5-inch rocket warhead fuzes, bomb, respectively, including provisions for process downtime.

[b] Prorated to reflect actual operating periods.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-24

METAL PARTS DECONTAMINATION SYSTEM OPERATING COST ESTIMATE[a]

	Units	Unit Cost ($)	90-mm Cartridge Units Required	90-mm Cartridge Cost ($ '000/yr)	3.5-inch Rocket Units Required	3.5-inch Rocket Cost ($ '000/yr)	5-inch Rocket Warhead Units Required	5-inch Rocket Warhead Cost ($ '000/yr)	MK-9 Depth Charge Units Required	MK-9 Depth Charge Cost ($ '000/yr)	M59A1 Semi-Armor Piercing Bomb Units Required	M59A1 Semi-Armor Piercing Bomb Cost ($ '000/yr)
Labor	manhours	15.00	9,800	147.0	10,400	156.0	2,000	30.0	4,500	67.5	3,100	46.5
Utilities												
• Electricity	kW-hr	0.05	78,300	3.9	83,200	4.2	15,700	0.8	30,000	1.5	20,000	1.0
• Water	1,000 gal	1.25	22	--	24	--	4	--	8	--	5	--
• Air	1,000 cf	0.75	12,000	9.0	13,000	9.8	2,400	1.8	4,500	3.4	3,010	2.3
• Fuel Oil	gal	1.00	10,500	10.5	11,200	11.2	2,100	2.1	4,000	4.0	2,700	2.7
Metal Recovery	1,000 lb	(20.00)	2,888	(57.8)	415	(8.3)	1,000	(20.0)	165	(3.3)	805	(16.1)
Maintenance (Labor and Materials)	4% of Total Fixed Investment[b]	--	--	108.3	--	115.1	--	21.7	--	49.5	--	34.0
General and Administrative Overhead	65% of Labor and Maintenance	--	-	165.9	--	176.2	--	33.6	--	76.1	--	52.3
	TOTAL OPERATING COST			386.8		464.2		70.0		198.7		122.7

[a]The Metal Parts Decontamination System is a multipurpose metal parts detoxification unit capable of processing a wide range of munition hardware; throughputs vary with munition type. Costs reflect processing of hardware from munitions containing 250,000 pounds of explosive. Operating periods are 175, 186, 35, 80, and 55 shifts/yr for the 90 mm cartridge, the 3.5-inch rocket, the 5-inch rocket warhead, the MK-9 depth charge and the M59A1 semi-armor piercing bomb, respectively, including provisions for process downtime.

[b]Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-25

BULK EXPLOSIVES INCINERATION SYSTEM OPERATING COST ESTIMATE[a]
(Explosives Incineration)

	Units	Unit Cost	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	2,900	43.5
Utilities				
• Electricity	kW-hr	0.05	98,000	4.9
• Water	1,000 gal	1.25	590	0.7
• Air	1,000 cf	0.75	4,200	3.2
• Fuel Oil	gal.	1.00	60,000	60.0
Maintenance (Labor and Material)	4% of Total Fixed Investment[b]	--	--	39.2
General and Administrative Overhead	65% of Labor and Maintenance[b]	--	--	53.8
	TOTAL OPERATING COST			205.3

[a]Costs pertain to a standard explosives incinerator capable of processing 550 lb/hr of energetic material with a six hour per shift operating period, but are for disposal of 250,000 lb/yr of explosives. Operating period is 90 shifts/yr, including provisions for system downtime.

[b]Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-26

BULK EXPLOSIVES INCINERATION SYSTEM OPERATING COST ESTIMATE[a]
(Explosives and Propellant Incineration)

	Units	Unit Cost	Units Required	Cost ($ '000/yr)
Labor	manhours	15.00	10,000	150.0
Utilities				
• Electricity	kW-hr	0.05	340,000	17.0
• Water	1,000 gal	1.25	2,045	2.6
• Air	1,000 cf	0.75	14,600	11.0
• Fuel Oil	gal.	1.00	210,000	210.0
Maintenance (Labor and Material)	4% of Total Fixed Investment[b]	--	--	136.0
General and Administrative Overhead	65% of Labor and Maintenance	--	--	185.9
	TOTAL OPERATING COST			712.5

[a]Costs pertain to a standard explosives incinerator capable of processing 550 lb/hr of energetic material with a six hour per shift operating period, but are for disposal of 250,000 lb/yr of explosives and 625,000 lb/yr of propellants. Operating period is 312 shifts/yr, including provisions for system downtime.

[b]Prorated to reflect actual operating period.

Source: Arthur D. Little, Inc. Estimates based on Reference 7

TABLE 4-27

OPERATING COST ESTIMATE FOR RESOURCE RECOVERY FROM THE NOTED MUNITIONS
(Explosives Removed by Hot Water Washout/Steamout)[a]
($ '000/yr)

	90-mm Cartridge	3.5-inch Rocket	5-inch Rocket Warhead	MK-9 Depth Charge	M59A1 Semi-Armor Piercing Bomb
Gun Ammunition Disassembly System	686.0	NA	136.9	NA	NA
Propellant Handling System	965.8	NA	NA	NA	NA
3.5-inch Rocket Disassembly System	NA	153.7	NA	NA	NA
Large Items Mechanical Reduction System	NA	NA	NA	73.4	166.2
Hot Water Washout/ Steamout System	498.2	467.5	428.0	311.3	281.8
Deactivation Furnace System	26.4	285.6	148.9	NA	NA
Metal Parts Decontamination System	386.8	464.2	70.0	198.7	122.7
TOTAL	631.6	1,371.0	783.8	583.4	570.7

[a] Operating costs are for processing 250,000 lb/yr of explosives from the noted munitions. They do not include the cost of refining the explosives at a central facility nor the value of the recovered explosives; for 2,000,000 lb/yr of explosives, these factors result in a net credit of $1,824,800.

NA = Not Applicable

Source: Arthur D. Little, Inc. Estimates

TABLE 4-28

OPERATING COST ESTIMATE FOR RESOURCE RECOVERY FROM THE NOTED MUNITIONS
(Explosives Removed by Meltout)[a]
($ '000/yr)

	90-mm Cartridge	3.5-inch Rocket	5-inch Rocket Warhead	MK-9 Depth Charge	M59Al Semi-Armor Piercing Bomb
Gun Ammunition Disassembly System	686.0	NA	136.9	NA	NA
Propellant Handling System	-965.8	NA	NA	NA	NA
3.5-inch Rocket Disassembly System	NA	153.7	NA	NA	NA
Large Items Mechanical Reduction System	NA	NA	NA	73.4	166.2
Meltout System[b]	323.9 (516.4)	NA (458.5)	73.1 (112.7)	89.2 (NA)	89.2 (NA)
Deactivation Furnace System	26.4	285.6	148.9	NA	NA
Metal Parts Decontamination System	386.8	464.2	70.0	198.7	122.7
TOTAL	457.3 (649.8)	NA (1,362.0)	428.9 (468.5)	361.3 (NA)	378.1 (NA)

[a] Operating costs are for processing 250,000 lb/yr of explosives from the noted munitions. They do not include the cost of refining the explosives at a central facility nor the value of the recovered explosives; for 2,000,000 lb/yr of explosives, these factors result in a net credit of $1,997,000.

[b] Numbers in parentheses pertain to Composition B-filled munitions; numbers not in parentheses pertain to TNT-filled munitions.

NA = Not Applicable

Source: Arthur D. Little, Inc. Estimates

TABLE 4-29

OPERATING COST ESTIMATES FOR CONTROLLED THERMAL DESTRUCTION OF NOTED MUNITIONS

(Explosives Removed by Hot Water Washout/Steamout)[a]

($ '000/yr)

	90-mm Cartridge	3.5-inch Rocket	5-inch Rocket Warhead	MK-9 Depth Charge	M59Al Semi-Armor Piercing Bomb
Gun Ammunition Disassembly System	686.0	NA	136.9	NA	NA
Propellant Handling System	196.7	NA	NA	NA	NA
3.5-inch Rocket Disassembly System	NA	153.7	NA	NA	NA
Large Items Mechanical Reduction System	NA	NA	NA	73.4	166.2
Hot Water Washout/ Steamout System	498.2	467.5	428.0	311.3	281.8
Deactivation Furnace System	26.4	285.6	148.9	NA	NA
Metal Parts Decontamination System	386.8	464.2	70.0	198.7	122.7
Bulk Explosives Disposal System	712.5	205.3	205.3	205.3	205.3
TOTAL	2,506.6	1,576.3	989.1	788.7	776.0

[a]Operating costs are for destruction of the noted munitions at a rate of 250,000 lb/yr of explosives.

NA = Not Applicable

Source: Arthur D. Little, Inc. Estimates

TABLE 4-30

OPERATING COST ESTIMATES FOR CONTROLLED THERMAL DESTRUCTION OF NOTED MUNITIONS[a]
(Explosives Removed by Meltout)
($ '000/yr)

	90-mm Cartridge	3.5-inch Rocket	5-inch Rocket Warhead	MK-9 Depth Charge	M59A1 Semi-Armor Piercing Bomb
Gun Ammunition Disassembly System	686.0	NA	136.9	NA	NA
Propellant Handling System	196.7	NA	NA	NA	NA
3.5-inch Rocket Disassembly System	NA	153.7	NA	NA	NA
Large Items Mechanical Reduction System	NA	NA	NA	73.4	166.2
Meltout System[b]	323.9 (516.4)	NA (458.5)	73.1 (112.7)	89.2 (NA)	89.2 (NA)
Deactivation Furnace System	26.4	285.6	148.9	NA	NA
Metal Parts Decontamination System	386.8	464.2	70.0	198.7	122.7
Bulk Explosives Disposal System	712.5	205.3	205.3	205.3	205.3
TOTAL	2,332.3 (2,524.8)	NA (1,567.3)	634.2 (673.8)	566.6 (NA)	583.4 (NA)

[a] Operating costs are for destruction of the noted munitions at a rate of 250,000 lb/yr of explosives.

[b] Numbers in parentheses pertain to Composition B-filled munitions; numbers not in parentheses pertain to TNT-filled munitions.

NA = Not Applicable

Source: Arthur D. Little, Inc. Estimates

Resource recovery involves the reclamation of useful resources from waste materials. The values of reclaimed materials were included in the operating cost estimates (as credits). The unit costs used to calculate these credits are (10,19,20):

- TNT - $0.74/pound;
- Composition B - $1.48/pound;
- Smokeless Powder - $1.86/pound; and
- Scrap Metal - $0.02/pound.

4.4.1 Case Study Analysis - Capital Investment Requirements

This case study pertains to the disposal of five specific types of munitions that are stored at eight army installations (as shown in Table 4-1). Relative capital investment requirements for implementing the five waste management options of interest at the eight Army installations considered in this case study can be estimated using the capital cost data base included in Sections 4.2 and 4.3.1. The appropriate capital investment requirements were identified for each installation considering:

- the process modules required for the specific munitions at the respective installation; and

- the availability of existing process equipment or facilities at each installation.

Figure 4-1 shows the process modules that pertain to controlled disposal of or resource recovery from the five munitions of interest, and Table 4-31 indicates the availability of these process modules at the eight Army installations considered in this case study. On the basis of the stockpile distribution at each installation (Table 4-1), the processing requirements for each munition (Figure 4-1), and the available process units at each site (Table 4-31), one can identify the process modules for which capital expenditures must be made on a site-by-site basis.

Table 4-31 indicates that open detonation facilities are available at all but one of the study sites, HWAAP. Since HWAAP is not able to practice open field disposal of munitions (i.e., regulatory authorities will no longer permit this practice), the "open detonation disposal option" must include a controlled thermal disposal system at HWAAP to allow for destruction of the HWAAP stockpile of obsolete and unserviceable munitions. However, the associated new capital investment is limited to $630,400, the cost of a 3.5-inch rocket disassembly system which is the only required processing unit not currently in place at HWAAP. The site-specific capital investment requirements associated with implementing the remaining four alternatives are summarized in Tables 4-32 through 4-35. Table 4-36 summarizes the total capital investment requirements for the five options considered in the case study. As can be seen from this table, the open detonation disposal option clearly has the lowest capital investment of the five options; the capital investment associated with this option is two orders of

MUNITION TYPE	RECOVERY PROCESS	Gun Ammunition Disassembly System	Propellant Handling System	3.5-inch Rocket Disassembly System	Large Items Mechanical Reduction System	Hot Water Washout/ Steamout System	Explosives Meltout System	Deactivation Furnace System	Metal Parts Furnace System	Bulk Explosives Incineration System	Dry Explosives Refining System	Wet Explosives Refining System
90-mm Cartridge	Steamout/Washout	B	B			B		B	B	D		R
	Meltout	B	B				B	B	B	D	R	
5-inch Rocket Warhead	Steamout/Washout	B				B		B	B	D		R
	Meltout	B					B	B	B	D	R	
3.5-inch Rocket	Steamout/Washout			B		B		B	B	D		R
	Meltout			B			B	B	B	D	R	
Depth Charge MK-9	Steamout/Washout				B	B			B	D		R
	Meltout				B		B		B	D	R	
Bomb, Semi-Armor Piercing	Steamout/Washout				B	B			B	D		R
	Meltout				B		B		B	D	R	

PROCESS MODULES (column group heading)

Key: B = module applicable to either explosives recovery or disposal
D = module applicable to explosives disposal only
R = module applicable to explosives recovery only

Figure 4-1 PROCESS MODULES APPLICABLE TO EACH MUNITION TYPE UNDER CONSIDERATION

TABLE 4-31

DEMILITARIZATION FACILITIES AVAILABLE AT ARMY INSTALLATIONS CONSIDERED IN CASE STUDY

Installation	Washout/Steamout/ Meltout Capabilities	Thermal Destruction Capabilities	Detonation Capabilities	Open Burning Capabilities
CAAA	1-Washout/Steamout Facility	2-Deactivation Furnaces	70 sites - 500 lb below ground	2 large sites
	1-Meltout Facility	1-Primper Popping Furnace		
HWAAP	1-Washout/Steamout Facility	1-Deactivation Furnace	None; cannot obtain required permits	None; cannot obtain required permits
	1-Meltout Facility	1-Metal Parts Furnace		
	1-Mechanical Reduction System	2-Bulk Explosives Incinerator		
	1-Ammunition Disassembly System			
	1-Propellant Handling System			
MAAP	2-Washout Facilities	1-APE 1236 Deactivation Furnace	10 sites - 150 lb with 4 ft earth cover	Area restricted until cages can be manufactured
NADA	1-APE 1300 Washout Facility	1-APE 1236 Deactivation Furnace	14 sites - 5,000 lb above ground/10,000 lb below ground with 6 ft earth cover	1 site with cage
		1-APE 1900 Deactivation Furnace		
PUDA	1-APE 1300 Washout Facility	1-APE 1236 Deactivation Furnace	14 sites - 50 lb above ground/4,000-20,000 lb below ground	4 sites, 1 cage

TABLE 4-31 (continued)

DEMILITARIZATION FACILITIES AVAILABLE AT ARMY INSTALLATIONS CONSIDERED IN CASE STUDY

Installation	Washout/Steamout/ Meltout Capabilities	Thermal Destruction Capabilities	Detonation Capabilities	Open Burning Capabilities
RRAD	1-APE 1300 Washout Facility	1-APE 1009 Deactivation Furnace	4 sites - 100 lb above ground/3,000 lb below ground, electrical firing systems	1 site - 50,000 lb; limited explosives
SIAD	None	1-APE 1236 Deactivation Furnace	14 sites - 10,000 lb above ground	2 sites - limited to explosives or explosives-contaminated wastes
TEAD	1-APE 1300 Washout Facility	2-APE 1236 Deactivation Furnaces (with afterburner)	9 sites - 100 lb above ground/5,000 lb below 8 ft cover; electrical firing systems	10 sites - 5,000 lb/site
	2-APE 1315 3.5-inch Rocket Disassembly Machines		10 sites - 100 lb above ground/10,000 lb below ground with 10 ft cover; electrical firing system	12 sites - 10,000 lb/site

Source: References 6 and 21

TABLE 4 32

TOTAL CAPITAL INVESTMENT - FACILITIES FOR RECOVERY OF EXPLOSIVES AFTER REMOVAL BY HOT WATER WASHOUT/STEAMOUT
($ '000)

	CAAP	HWAAP	MAAP	NADA	PUDA	RRAD	SIAD	TEAD	Central Refinery
Gun Ammunition Disassembly System	NA	NR	4,047.2	4,047.2	4,047.2	NA	4,047.2	NA	NA
Propellant Handling System	NA	NA	NA	1,076.7	NR	NA	1,076.7	NA	NA
3.5 Inch Rocket Disassembly System	NA	630.4	630.4	NA	630.4	630.4	630.4	NR	NA
Large Items Mechanical Reduction System	974.2	NR	NA	NA	NA	NA	NA	NA	NA
Hot Water Washout/Steamout System	NR	NR	NR	1,992.2	NR	NR	1,992.2	NR	NA
Deactivation Furnace System	NA	NR	NR	NR	NR	NR	NR	NR	NR
Metal Parts Decontamination System	4,023.8	NR	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8	NA
Wet Explosives Refining System	NA	NA	NA	NA	NA	NA	NA	NA	2,056.6
TOTAL	4,998.0	630.4	8,701.4	11,139.9	8,701.4	4,654.2	11,770.3	4,023.8	2,056.6

NA = Process Module Not Applicable to Disposal of the Munitions Considered for this Study and Located at the Respective Installation

NR = Process Equipment Currently In place at the Respective Installation; New Capital Expenditures Not Required

Source: Arthur D. Little, Inc. Estimates

TABLE 4-33

TOTAL CAPITAL INVESTMENT - FACILITIES FOR RECOVERY OF EXPLOSIVES AFTER REMOVAL BY MELTOUT
($ '000)

	CAAP	HWAAP	MAAP	NADA	PUDA	RRAD	SIAD	TEAD	Central Refinery
Gun Ammunition Disassembly System	NA	NR	4,047.2	4,047.2	4,047.2	NA	4,047.2	NA	NA
Propellant Handling System	NA	NA	NA	1,076.7	NR	NA	1,076.7	NA	NA
3.5 Inch Rocket Disassembly System	NA	630.4	630.4	NA	630.4	630.4	630.4	NR	NA
Large Items Mechanical [illegible] System	[illegible]	NR	NA	NA	NA	NA	NA	NA	NA
[illegible] System	NR	NR	1,107.2	1,107.2	1,107.2	1,107.2	1,107.2	1,107.2	NA
[illegible]	NA	NR	NR	NR	NR	NR	NR	NR	NA
[illegible] System	4,023.8	NR	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8	NA
Dry Explosives Refining System	NA	NA	NA	NA	NA	NA	NA	NA	1,549.9
TOTAL	4,998.0	630.4	9,808.6	10,254.9	9,808.6	5,761.4	10,885.3	5,131.0	1,549.9

NA = Process Module Not Applicable to Disposal of the Munitions Considered for this Study and Located at the Respective Installation

NR = Process Equipment Currently In place at the Respective Installation; New Capital Expenditures Not Required

Source: Arthur D. Little, Inc. Estimates

TABLE 4-34

TOTAL CAPITAL INVESTMENT - FACILITIES FOR DISPOSAL OF EXPLOSIVES AFTER REMOVAL BY HOT WATER WASHOUT/STEAMOUT
($ '000)

	CAAP	HWAAP	MAAP	NADA	PUDA	RRAD	SIAD	TEAD
Gun Ammunition Disassembly System	NA	NR	4,047.2	4,047.2	4,047.2	NA	4,047.2	NA
Propellant Handling System	NA	NA	NA	1,076.7	NR	NA	1,076.7	NA
3.5-inch Rocket Disassembly System	NA	630.4	630.4	NA	630.4	630.4	630.4	NR
Large Items Mechanical Reduction System	974.2	NR	NA	NA	NA	NA	NA	NA
Hot Water Washout/Steamout System	NR	NR	NR	1,992.2	NR	NR	1,992.2	NR
Deactivation Furnace System	NA	NR	NR	NR	NR	NR	NR	NR
Metal Parts Decontamination System	4,023.8	NR	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8
Bulk Explosives Incineration System	2,833.1	NR	2,833.1	2,833.1	2,833.1	2,833.1	2,833.1	2,833.1
TOTAL	7,831.1	630.4	11,534.5	13,973.0	11,534.5	7,487.3	14,603.4	6,856.9

NA = Process Module Not Applicable to Disposal of the Munitions Considered for this Study and Located at the Respective Installation

NR = Process Equipment Currently In-place at the Respective Installation; New Capital Expenditures Not Required

Source: Arthur D. Little, Inc. Estimates

TABLE 4-35

TOTAL CAPITAL INVESTMENT - FACILITIES FOR DISPOSAL OF EXPLOSIVES AFTER REMOVAL BY MELTOUT
($ '000)

	CAAP	HWAAP	MAAP	NADA	PUDA	RRAD	SIAD	TEAD
Gun Ammunition Disassembly System	NA	NR	4,047.2	4,047.2	4,047.2	NA	4,047.2	NA
Propellant Handling System	NA	NA	NA	1,076.7	NR	NA	1,076.7	NA
3.5-inch Rocket Disassembly System	NA	630.4	630.4	NA	630.4	630.4	630.4	NR
Large Items Mechanical Reduction System	974.2	NR	NA	NA	NA	NA	NA	NA
Meltout System	NR	NR	1,107.2	1,107.2	1,107.2	1,107.2	1,107.2	1,107.2
Deactivation Furnace System	NA	NR	NR	NR	NR	NR	NR	NR
Metal Parts Decontamination System	4,023.8	NR	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8	4,023.8
Bulk Explosives Incineration System	2,833.1	NR	2,833.1	2,833.1	2,833.1	2,833.1	2,833.1	2,833.1
TOTAL	7,831.1	630.4	12,641.7	13,088.0	12,641.7	8,594.5	13,718.4	7,964.1

NA = Process Module Not Applicable to Disposal of the Munitions Considered for this Study and Located at the Respective Installation

NR = Process Equipment Currently In-place at the Respective Installation; New Capital Expenditures Not Required

Source: Arthur D. Little, Inc. Estimates

TABLE 4-36

SUMMARY OF CAPITAL INVESTMENT REQUIREMENTS FOR CASE STUDY

Waste Management Option	Explosives Removal Method	Capital Investment ($ '000,000)
Open Detonation	None	0.6
Controlled Thermal Destruction	Hot Water Washout/Steamout	74.5
	Meltout	77.1
Resource Recovery	Hot Water Washout/Steamout	56.7
	Meltout	58.8

Source: Arthur D. Little, Inc. Estimates

magnitude lower than those of the remaining options. However, the future for continued practice of this option is uncertain, and economic factors may not dictate the preferred method. If open detonation must be discontinued due to environmental regulations or policy restrictions, the comparison would be distilled to an evaluation of the relative economic attractiveness of the remaining options. When their capital requirements are compared, the resource recovery options are more attractive than the controlled thermal disposal options. The capital investment associated with resource recovery is roughly 75 percent of that for controlled thermal destruction. Within these two broad categories of waste management options, two explosives removal options were considered (i.e., hot water washout/steamout versus meltout). Differences in costs associated with these two explosives removal options are minimal (i.e., generally less than five percent).

4.4.2 Case Study Analysis - Annual Operating and Maintenance Costs

Annual operating and maintenance cost estimates were developed for the five waste management options for obsolete and unserviceable munitions described in the preceding section. Operating and maintenance costs have been found to vary with munition type, and, consequently, it was necessary to identify a representative annual workload of munitions to be considered in this case study. Table 4-37 presents a first year operating plan for handling the obsolete and unserviceable munitions that are under consideration in this case study. This plan was developed on the following basis:

- ARDC determined that two million pounds of explosives should be processed annually.

- To the maximum practical extent, the affected installations should process equal shares of the stockpile; since there are eight installations, each was expected to process 250 thousand pounds of explosives annually.

- In cases where it was not feasible for an installation to process 250 thousand pounds of explosives per year (e.g., the Sierra Army Depot [SIAD] stockpile of the munitions of interest represents only 165,860 pounds of explosives), that installation would process the maximum number of munitions possible.

- Hawthorne Army Ammunition Plant (HWAAP) has a large scale demilitarization facility in place which could handle in excess of 250 thousand pounds of munitions per year. Thus, this installation would be expected to process excess munitions to make up for throughput shortfalls at other installations.

- A representative distribution of munition types was specified.

- Since TNT accounts for approximately 25 percent of the explosives contained in the munitions selected for this case study, 500 thousand pounds of TNT would be expected to be

TABLE 4-37

CASE STUDY FIRST YEAR OPERATING PLAN

Installation	Munition	TNT-Filled Munitions			Composition B Filled Munitions		
		Quantity	Fill (lb/round)	Explosive Processed (lb)	Quantity	Fill (lb/round)	Explosive Processed (lb)
CAAA	Bomb, Semi-Armor Piercing	794	315	250,110	0	0	0
HWAAP	Depth Charge, MK-9	1,211	190	230,090	0	0	0
	Warhead, Rocket, 5-inch	0	0	0	6,929	15	103,935
MAAP	Warhead, Rocket, 5-inch	0	0	0	16,667	15	250,005
NADA	Cartridge, 90-mm	0	0	0	125,000	2	250,000
PUDA	Rocket, 3.5-inch	0	0	0	132,979	1.88	250,000
RRAD	Rocket, 3.5-inch	0	0	0	132,979	1.88	250,000
SIAD	Rocket, 3.5-inch	0	0	0	51,184	1.88	96,226
	Cartridge, 90-mm	9,900	2	19,800	24,917	2	49,834
TEAD	Rocket, 3.5-inch	0	0	0	132,979	1.88	250,000
	TOTAL			500,000			1,500,000

Source: Arthur D. Little, Inc. Estimates based on References 11 and 12

processed per year; Composition B would be processed at a rate of 1.5 million pounds per year.

It should be noted that Table 4-37 represents first year operating conditions; in subsequent years the operating plan would change significantly. The munitions selected for consideration in this case study are not distributed evenly among the eight installations at which they are stored, and, consequently, operations during subsequent years would, under realistic circumstances, involve the processing of different munitions by installations which depleted their inventories of the five munitions considered for this study. However, the first year operating plan allows for the development of first year operating and maintenance costs which are expected to illustrate the relative economies of operating the five waste management options of interest.

Table 4-38 presents first year operating and maintenance cost estimates for resource recovery from and thermal treatment of obsolete and unserviceable conventional ammunition. As can be seen from this table, open detonation offers significant cost advantages over the other options. However, it has been noted that the future outlook for continued practice of open detonation is uncertain, in which case, the relative economic merits of resource recovery and controlled thermal destruction must be compared. In this case, both resource recovery options provide significant economic advantages over the controlled thermal destruction options. The operating and maintenance costs associated with controlled thermal combustion are nearly double the costs of resource recovery.

It should also be noted that different explosives removal methods contribute significantly to differences in costs among the two resource recovery options considered. The resource recovery option that incorporated a meltout system exhibited an operating and maintenance cost that was less than 85 percent of the operating and maintenance cost for the resource recovery option that included a hot water washout/steamout system. The cost differences attributed to different explosives removal processes are somewhat less extreme (i.e., less than ten percent) for the two controlled thermal destruction options considered.

TABLE 4-38

FIRST YEAR OPERATING COST ESTIMATES FOR MANAGEMENT OF THE CASE STUDY MUNITIONS

Installation	Munition	Explosive Fill		Resource Recovery Costs ($ '000/yr)		Controlled Disposal Costs ($ '000/yr)		Open Detonation Costs ($ '000/yr)
		Type	Quantity (lb)	Washout/Steamout Explosives Removal Process	Meltout Explosives Removal Process	Washout/Steamout Explosives Removal Process	Meltout Explosives Removal Process	
CAAA	Bomb, Semi-Armor Piercing	TNT	250,110	571.0	378.3	776.3	583.7	26.2
HWAAP	Depth Charge, MK-9	TNT	230,090	536.9	332.5	725.9	521.5	521.5[a]
	Warhead, Rocket, 5-inch	Comp B	103,935	325.9	194.8	411.2	280.1	280.1[a]
MAAP	Warhead, Rocket, 5-inch	Comp B	250,005	783.8	468.5	989.1	673.8	72.5
NADA	Cartridge, 90-mm	Comp B	250,000	631.6	649.8	2,506.6	2,524.8	356.3
PUDA	Rocket, 3.5-inch	Comp B	250,000	1,371.0	1,362.0	1,576.3	1,567.3	272.6
RRAD	Rocket, 3.5-inch	Comp B	250,000	1,371.0	1,362.0	1,576.3	1,567.3	272.6
SIAD	Rocket, 3.5-inch	Comp B	96,226	527.7	524.2	606.7	603.3	104.9
	Cartridge, 90-mm	Comp B	49,834	125.9	129.5	499.7	503.3	71.0
	Cartridge, 90-mm	TNT	19,800	50.0	36.2	198.5	184.7	28.2
TEAD	Rocket, 3.5-inch	Comp B	250,000	1,371.0	1,362.0	1,576.3	1,567.3	272.6
Central Refinery			--	(1,824.8)	(1,997.1)	0.0	0.0	0.0
	TOTAL			5,841.0	4,802.7	11,442.9	10,577.1	2,278.5

[a] HWAAP cannot obtain the necessary permits for open detonation; costs pertain to disposal by controlled thermal methods.

Source: Arthur D. Little, Inc. Estimates

SECTION 5

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