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NAVAIR

Evaluation of Alternative Technologies to Open Detonation for Treatment of Energetic Wastes at the Naval Air Weapons Station, China Lake, California

JANUARY 2004

NAVAL AIR WARFARE CENTER WEAPONS DIVISION
CHINA LAKE, CA 93555-6100

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Naval Air Warfare Center Weapons Division

FOREWORD

The purpose of this document is to evaluate the feasibility of using technologies other than Open Detonation (OD) for treating the many and varied energetic wastes generated by the Naval Air Systems Command Weapons Division (NAVAIR WD) at the Naval Air Weapons Station (NAWS), China Lake, California. This report documents the identification, screening, and initial evaluation of potential alternatives to the treatment of energetic wastes by OD at China Lake. This document describes China Lake's energetic wastestreams and potential alternatives to OD treatment, and evaluates the applicability of these alternative technologies to China Lake's energetic wastestreams. This evaluation was specifically carried out for the wastestreams currently generated at China Lake and may not be applicable to other facilities and uses.

This report was prepared for timely presentation of information and is released at the working level.

Approved by
C. F. MARKARIAN, *Head*
Research Department
29 January 2004

Under authority of
D. J. VENLET
RDML, U.S. Navy
Commander

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K. HIGGINS
Director for Research and Engineering

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(U) This report documents the identification, screening, and initial feasibility evaluation of potential alternatives to Open Detonation (OD) for treatment of energetic wastestreams generated from research, development, test, and evaluation (RDT&E) activities at the Naval Air Weapons Station (NAWS), China Lake, California.

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ABSTRACT

This report documents the identification, screening, and initial feasibility evaluation of potential alternatives to Open Detonation (OD) for treatment of energetic wastestreams generated from research, development, test, and evaluation (RDT&E) activities at the Naval Air Weapons Station (NAWS), China Lake, California.

OBJECTIVE

The objective of this task is to evaluate the feasibility and safety of using technologies other than OD for treating the many and varied energetic wastes generated by the Naval Air Systems Command Weapons Division (NAVAIR WD) at NAWS, China Lake, California. Ultimately, an alternative will only be considered for implementation if it offers advantages when compared with the current treatment method of OD.

BACKGROUND

China Lake is the Navy's largest RDT&E facility for weapons development and testing. It consists of 1.1 million acres of land in California's remote and sparsely populated Mojave Desert (Figure 1). Much of the surrounding land is either owned or controlled by the U.S. government.

FIGURE 1. China Lake's Land (Shown in Orange) and Airspace (Shown in Blue).

As a result of activities associated with its RDT&E mission, China Lake generates a diverse energetic wastestream. Department of Transportation, Department of Defense (DOD), and Navy regulations prohibit the transport of most of the energetic wastes generated at China Lake off-base, either because they are R&D materials that have not been fully classified with respect to explosive safety, or because they have been altered or damaged through T&E activities. Currently, OD is the primary method of treating energetic wastes at China Lake. Open Burning (OB) is only used occasionally for special circumstances. The last OB was August 1998.

China Lake operates one site for the treatment of energetic wastes by OD (Figure 2). The site is in a remote canyon 2,760 feet above sea level and 7 miles from the nearest base boundary, which is to the east. The nearest base boundary in the dominant wind direction is 17 miles to the northeast, while the nearest town (Trona) is located 9 miles to the southeast. A groundwater monitoring well at the site indicates that the water table is more than 400 feet below the surface. The nearest surface water is on the base, 4 miles to the west at an altitude of 2,165 feet above sea level. Mountains surround the OD site, 1,400 feet higher than the site to the north and 700 feet higher to the south, creating a natural amphitheater. The mountainous terrain mitigates the noise and shock waves from the OD blasts. Additionally, the site is located in rocky terrain well outside the habitats of the desert tortoise and other sensitive species.

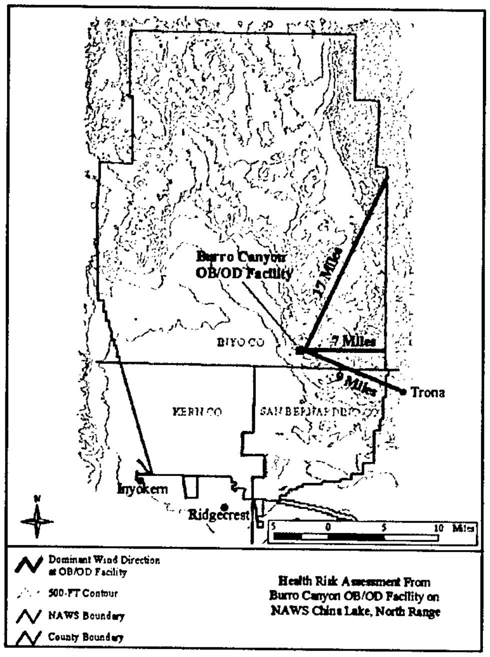

FIGURE 2. China Lake's Open Detonation Site Location.

Although the ideal location of China Lake's OD treatment site enables us to conduct the OD treatment of our energetic wastes safely and in compliance with environmental regulations, we are sensitive to concerns expressed by the public regarding activities at other OD treatment facilities. In the last 20 years, significant advances have been made in the development of alternatives to OD. This report documents our proactive efforts to be informed about the current status and applicability of alternatives to OD for the treatment of energetic wastes at China Lake.

APPROACH

The objective of this task is to evaluate the feasibility of using technologies other than OD for treating the many and varied energetic wastes generated at China Lake. To accomplish this, the following approach was used:

Step 1. Identify and describe China Lake's energetic wastestream.

Step 2. Identify safety issues.

Step 3. Identify and categorize alternative technologies to OD.

Step 4. Screen the technologies for general applicability to China Lake's energetic wastestreams and technology maturity.

Step 5. Provide more information about the technologies that pass the initial screening.

Step 6. Evaluate the technologies for specific application to China Lake's energetic wastestreams and compare them with the current treatment method (OD).

This document follows the same order as the above approach.

STEP 1. IDENTIFICATION AND DESCRIPTION OF CHINA LAKE'S ENERGETIC WASTESTREAM

China Lake is not a demilitarization facility. We treat only the energetic wastes generated on-site as a result of China Lake's weapons RDT&E mission. Regulations prohibit most of the energetic wastes generated at China Lake from being transported on public roadways, either because they are R&D materials that have not been fully classified for transportation, or because they have been damaged or otherwise altered through T&E activities.

Activities at China Lake generate a diverse energetic wastestream. The wastestream may be described both physically and chemically. The physical descriptions of China Lake's energetic wastes range from residues of experimental energetic formulations on a tissue, to complete ordnance systems (such as bombs and missiles) that have been damaged or otherwise altered through testing and evaluation. The chemical descriptions of China Lake's energetic wastes vary even more than the physical descriptions of the waste items. These chemical descriptions have been grouped into nine families of propellants, six families of explosives, and two miscellaneous families. A list of these families is included as Table 1.

TABLE 1. Energetic Families.

EXPLOSIVES	
Melt cast explosives	
A1	TNT based (Comp-B, Cyclotol, Octol)
A2	TNT / aluminum (H-6)
Plastic-bonded explosives (PBXs)	
B1	Nitramine / binder
B2	Nitramine / binder / aluminum
B3	Nitramine / binder / aluminum / AP
Other explosives	
C1	e.g., PbN3, ammonium picrate
PROPELLANTS	
Gun propellant	
IA	Single base (NC)
IA	Double base (NC / NG)
IA	Triple base (NC / NG / NQ)
Rocket/missile propellant	
IIA	Double base with lead
IIB	Double base without lead
IIC	AP / binder / aluminum
IID	AP / binder / aluminum / nitramines (>50% AP)
IIE	AP / binder reduced smoke
IIF	Nitramine / energetic binder / aluminum / <20% AP
MISCELLANEOUS	
P	Pyrotechnics
W	Energetic contaminated wastes (ECW)

Although the diversity of China Lake's energetic wastestream is vast, it must be grouped into distinct treatability categories to assess the feasibility and applicability of specific alternative treatment technologies. There are two primary energetic waste characteristics to be considered when assessing a treatment method: (1) the physical form of the waste and (2) the chemical composition. Although many of the alternative technologies in development are limited by the chemical composition of the energetic waste, the specific physical forms of the waste item (e.g., powders, confined munitions) limit the applicability of virtually all of the alternative treatment methods. Therefore, *for the purpose of evaluating the alternatives*, a decision was made to group the China Lake energetic wastes into four categories based only on their physical forms, even though the chemical compositions within a category will vary considerably. Specific chemical composition limitations of the wastes will be noted in the description of each technology when the information is available. The four energetic waste categories are described below.

Bulk Energetics. This category includes "unconfined" energetic wastes, such as blocks, pellets, chunks, powders, and liquids; energetic-contaminated wastes, such as cotton rags, gloves, plastic beakers and buckets (primarily polyethylene), aluminum foil, and post-test debris; and energetic contaminated containers, such as wood crates, cardboard boxes, velostat bags, and cellulose drums.

Small Cased Munitions. These items have confined energetics and contain 0.5 pound or less of energetic material in each item. This category includes cartridge-actuated devices (CADs), propellant-actuated devices (PADs), exploding bolts, fuzes, small projectiles (15 to 30mm, 50-caliber), bullets, bomblets, gas pressure generators, booster pellets, detonators, igniters, leads, thermal batteries, and numerous other small items. The casings for the items in this category are typically thin metal, such as a bullet cartridge. In addition to the hazards of and the potential damage from the confined energetic materials, the metal casings may create some additional hazards and damage during a detonation.

Medium Cased Munitions. These items have confined energetics and contain between 0.5 and 100 pounds of energetic materials in each item. This category includes bomblets, warheads, rocket motors, projectiles (81 to 152 millimeters), propellant charges for projectiles, grenades, mines, flares, sectioned munitions, all-up missiles, and numerous other types of items. The casings for the items in this category may be thin or thick. In addition to the hazards of and the potential damage from the confined energetic materials, the metal casings may create significant additional hazards and damage during a detonation. Thick metal casings are typical in warheads and projectiles and if detonated, a significant quantity of both large and small fragments would be created. These fragments would have high velocities and travel significant distances. This is a major consideration in evaluating alternative technologies.

Large Cased Munitions. These items have confined energetics and contain 100 pounds or more of energetic materials in each item. (Range for 4 years surveyed was 100 to 3,800 pounds. Range limit is 15,000 pounds per event. The largest single item ever treated contained approximately 12,000 pounds of energetic material.) This category includes bombs, rocket motors, warheads, sectioned munitions, and all-up missiles. The casings for the items in this category may be thin or thick. In addition to the hazards of and the potential damage from the confined energetic materials, the metal casings will create significant additional hazards and damage during a detonation. Thick metal casings are typical in warheads and bombs and if detonated, a significant quantity of both large and small fragments would be created. These fragments would have high velocities and travel significant distances. This is a major consideration in evaluating alternative technologies.

A tabulation of the China Lake energetic wastestreams, grouped into categories based on physical form previously described, for tracking years 1998 through 2001 is summarized in Table 2. The apparent reduction in wastestream is a result of the cyclic nature of our workload, which depends on varying requirements for different fiscal years; it should not be interpreted as an indication of future requirements.

TABLE 2. Tabulation of China Lake's Energetic Wastestreams for Tracking Years 1998 Through 2001.

Wastestream category	Tracking year (July to July)				Average lb[a] (% of waste)
	1998/1999, lb[a]	1999/2000, lb[a]	2000/2001, lb[a]	2001/2002, lb[a]	
Bulk energetics[b] (% of waste)	12,000 (22%)	8,000 (22%)	12,000 (46%)	27,000 (64%)	15,000 (37%)
Small cased munitions[c] (% of waste)	2,000 (4%)	2,000 (6%)	1,000 (4%)	1,000 (2%)	2,000 (5%)
Medium cased munitions[c] (% of waste)	7,000 (13%)	3,000 (8%)	5,000 (19%)	3,000 (7%)	5,000 (12%)
Large cased munitions[c] (% of waste)	33,000 (61%)	23,000 (64%)	8,000 (31%)	11,000 (26%)	19,000 (46%)
Subtotal of waste only	54,000	36,000	26,000	42,000	41,000
Donor (% of total treated)	84,000 (61%)	39,000 (52%)	10,000 (28%)	12,000 (22%)	36,000 (47%)
Total treated by OD at China Lake	**138,000**	**75,000**	**36,000**	**54,000**	**77,000**

[a] Rounded to the nearest 1,000 pounds. Calculations use rounded numbers.

[b] Includes bulk energetic and waste contaminated with energetics.

[c] Includes the actual weight of the explosive components without casing.

STEP 2. IDENTIFICATION OF SAFETY ISSUES

Safety issues present the most significant constraints when evaluating alternative treatment methods for the energetic wastes generated at China Lake. Propellants and explosives are an intimate mixture of fuel and oxidizer ingredients. The amounts of fuel and oxidizer are balanced for complete reaction and maximum energy output. Once a propellant or explosive is initiated, the energy release is extremely rapid and almost impossible to stop. Because the reactions are so rapid and so violent, safety is of prime importance when working with propellants, explosives, and ordnance containing these energetic materials. One of the fundamentals of safety is to minimize the exposure of people and equipment to these materials.

At China Lake the situation is even more acute due to the RDT&E mission. In R&D, scientists and engineers are synthesizing new experimental ingredients; formulating new experimental propellants and explosives; and devising new concepts for motors, bombs, and warheads. In doing this R&D, the scientists and engineers are pushing the existing knowledge base. Some of the ingredients and formulations are found to be too dangerous for further scale-up and development. There have been incidents where, for example, propellant has inadvertently ignited when samples simply rubbed against one another. These dangerous materials need to be treated in the safest manner possible to reduce the likelihood of serious injury or death.

In T&E, new materials and concepts (as well as materials that have been in the Fleet) are tested in several different environments. For example, to ensure that items are safe for storage and use on board ships, ordnance is dropped from a height of 40 feet, vibrated at various frequencies and amplitudes, and subjected to temperature and humidity cycles and many other tests. In the testing process the propellants and explosives may become damaged, which makes them much more sensitive to thermal and mechanical shock stimuli. For example, propellants that have been modestly damaged to 1% voids (a very small amount of damage that is almost impossible to detect via normal x-ray) can have their sensitivity to mechanical shock increased by an order of magnitude. Severely damaged propellants or propellant powders can easily transition from a burning reaction to a detonation.

Department of Transportation, DOD, and Navy regulations prohibit the transport of most of China Lake's energetic wastes on public roads or railways because of the unique dangers associated with the energetic wastes produced during RDT&E operations.

China Lake places great emphasis on the safety and health of its employees, especially those performing potentially dangerous operations such as working with propellants and explosives. The treatment of energetic wastes in a safe manner compliant with all health and safety regulations is of prime importance. An Operational Risk Management (ORM) study of the hazards is performed for all operations associated with the handling of energetic materials. The ORM addresses the risks of an operation with respect to probability of occurrence and severity. The combination of probability of occurrence and severity determine a Risk Assessment Code (RAC). The ORM study for the OD of energetic wastes at China Lake indicates that this operation is within acceptable risk limits, provided excessive unpacking or manipulation of energetic waste is avoided. An ORM study for any alternative treatments considered would have to be done before a final decision for implementation is made. *Because of the variety and unpredictable explosive hazards of most of China Lake's energetic wastes, it is likely that most forms of pretreatment that involve cutting, grinding, or other significant manipulation of the energetic material would not have acceptable risk limits.* These operations would greatly increase the unpacking and manipulation requirements for the energetic wastes. Increases in the exposure and handling of energetics, especially energetic waste, increase the probability of an incident occurring that causes a serious injury or death.

STEP 3. IDENTIFICATION AND CATEGORIZATION OF ALTERNATIVE TECHNOLOGIES

Numerous sources were used to identify and obtain information about alternative technologies. Of special note are:

1. *Joint Demilitarization Study*, Joint Ordnance Commanders Group Munitions Demil/Disposal Subgroup, July 1999 (Reference 1)
2. Proceedings from the *9th Demil Users Group* meeting (Reference 2)
3. Proceedings from the 2000 and 2001 *Global Demilitarization Symposium and Exhibition* (References 3 and 4)
4. Internet
5. Munitions Items Disposition Action System (MIDAS) website*
6. Literature search
7. *Closed Technology Study*, Joint Ordnance Commander's Group, September 2001 (Reference 5)

The technologies identified as potential alternatives to OD are grouped into two categories: destruction technologies, and recovery and reuse technologies.

In addition, pretreatment technologies that facilitate either the removal of energetic material from the casing or the disassembly of munitions, and wastestream treatment technologies that treat secondary wastestreams are listed. Figure 3 illustrates how these technology categories fit together. Table 3 is a comprehensive list of the technologies identified by category, with a brief description of each. All technologies are included in Table 3, regardless of their level of maturity or their applicability to China Lake's energetic wastestream.

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* http://206.37.241.30/.

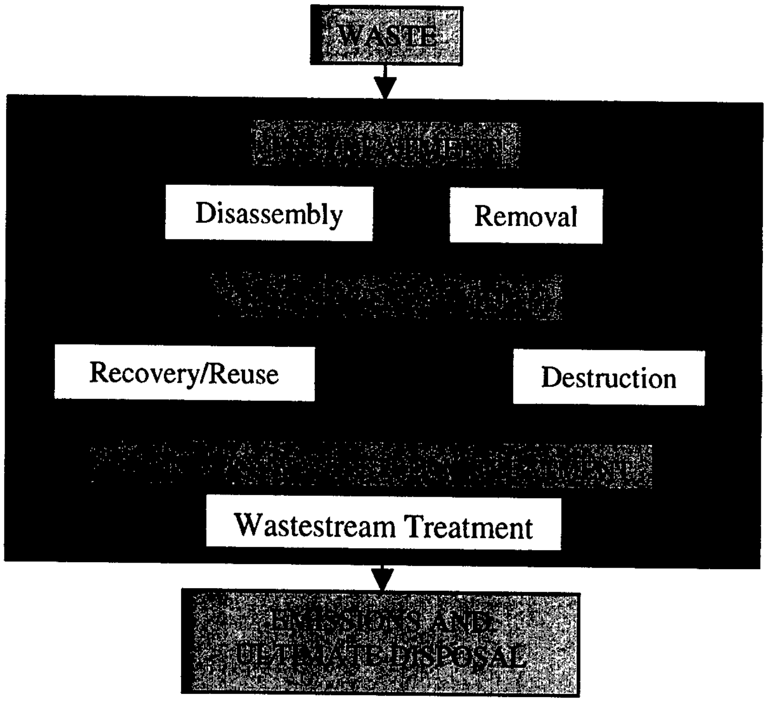


FIGURE 3. Technology Categories.

TABLE 3. Identified Technologies With Description Summaries.

Technology	Description
Disassembly (pretreatment)	
Flexible Workcell/Robotic Disassembly	Robotics unpack, handle, repack, and help in the disassembly process.
Laser Cutting of Munitions	Ultra-short laser pulses ablate the energetic with virtually no heat transfer to the surrounding material. This is an alternative to conventional explosive machining.
Removal technologies (pretreatment)	
Washout, High-Pressure Waterjet	A high-pressure washout nozzle directs streams of water against the energetic. The energetic is eroded, removed, and collected.
Washout, Steam	Steam removes TNT-based explosives.
Washout, Carbon Dioxide	A carbon dioxide pellet blaster removes press-loaded explosives.
Washout, Liquid Nitrogen	High-pressure liquid nitrogen erodes and thermally spalls propellant from a rotating rocket motor. The propellant would be collected for reuse or treatment.
Meltout, Microwave	Microwaves melt out TNT-based explosive.

TABLE 3. (Contd.)

Technology	Description
Removal technologies (pretreatment) (contd)	
Dry Machining	Energetics are removed from their casings by machining.
Cryofracturing, Cryocycling	Liquid nitrogen freezes energetics/munitions and then fractures them for size reduction of large pieces of energetics or to "disassemble" small cased munitions.
Ultrasonic Removal	Focused ultrasonic energy fragments the cast-loaded energetics and enables removal. Recovery/reuse would follow.
Destruction technologies (primary treatment)	
Open Burn	Traditional method.
Open Detonation	Traditional method.
Contained Detonation	Energetics are detonated inside a steel chamber, constructed to dampen the blast. After-burning reactions are suppressed to protect the integrity of the chamber. Particulates are filtered from the detonation gases.
Contained Burn #1, Solid Rocket Motors	Rocket motors are burned in a confined chamber. The combustion gases are contained, treated, and released.
Contained Burn #2, Confined Burn Facility	Energetic wastes are burned in a blast-reinforced chamber. The combustion gases are contained, treated, and released to the atmosphere.
Contained Burn #3, Energetic-Contaminated Wastes	Similar to the "Confined Burn Facility," but more applicable to combustible waste (e.g., rags, gloves, wipes, pallets, plastic, etc.) contaminated with small amounts of energetics materials.
Incineration, Rotary Kiln	Enclosed incinerator. Rotary kiln slowly moves waste from one end to the other. Waste detonates or combusts. Emissions are treated. Uniform wastestreams are treated most efficiently. Small explosive items with casings are okay (<40 grams energetics) in some units.
Incineration, Plasma Arc	Molten slag (soil with iron fluxing agent) destroys organic compounds and traps inorganic compounds. Emissions are treated. Enclosed alternative to incineration.
Incineration, Fluidized Bed	Waste is injected into a turbulent bed of hot sand, created by forced air. Emissions are treated. Limited to liquids, slurries, and powders with low inorganic content. Enclosed incinerator.
Oxidation, Base Hydrolysis	Waste is heated to mild temperatures (90 to 150°C) and usually elevated pressures (200 psig) with a strong base (pH > 12). Energetic waste is converted to water-soluble, non-energetic products. Resulting solution is still hazardous and must be treated.

TABLE 3. (Contd.)

Technology	Description
Destruction technologies (primary treatment) (contd)	
Oxidation, Supercritical Water (Hydrothermal Oxidation)	Organic waste, water, and an oxidant (e.g., air or oxygen) are subjected to high temperature and pressure (> 374°C, > 3,000 psig). Organics are decomposed. Very severe operating requirements and usually reserved for the nastier, more difficult-to-treat wastes.
Oxidation, Molten Salt	Air and waste are injected into a molten salt bed. The product gases are forced to pass through the molten salt before exiting, which results in good retention of metals and acidic gases. Operating temperatures are typically from 850 to 1,000°C.
Oxidation, Electrochemical	An electrochemical cell is used to destroy organic waste. Organic liquids are oxidized either directly by metal ions, or by other oxidizing compounds produced from reactions involving the metal ions. This technology is being considered for destruction of primary explosives such as azides and styphnates, but has not been developed for this application yet.
Oxidation, Wet Air	Aqueous phase oxidation is used to treat organic and inorganic wastes at elevated temperatures (150 to 320°C) and pressures (300 to 3,000 psig). Similar to supercritical water oxidation (SCWO), but with slightly lower temperatures and pressures. Limited to slurries and liquids.
Oxidation, Peroxydisulfate	An aqueous process that uses sodium or ammonium-peroxydisulfate to destroy organic liquids or solids.
Oxidation, Adams Sulfur	Organic wastes are reacted in an atmosphere of elemental sulfur vapor at low temperatures. Products are carbon-sulfur residue, hydrogen sulfide gas, and sulfides. Emissions must be treated.
Molten Metal	A molten metal medium destroys energetic wastes.
Hypergolic Non-Detonative Neutralization	Bulk energetic wastes are reacted with a hypergolic chemical (the combination would instantly ignite), which neutralizes the energetic waste in a controlled exothermic reaction.
Charged Particle Beam	Energetic electron beams detect and detonate high explosives. Applicable for clearance of unexploded ordnance from military ranges.

TABLE 3. (Contd.)

Technology	Description
Recovery and reuse (primary treatment)	
Liquid Ammonia Extraction	Propellant and explosive fuel and oxidizer ingredients are extracted, separated, and recovered using liquid ammonia.
Reuse Solid Propellant for Commercial Mining/ Quarry Applications	Reformulation of reclaimed explosives and propellants into commercial blasting explosives for use in mining application.
Commercial Resale	Sale of obsolete U.S. munitions to foreign governments.
Chemical Conversion	Chemical conversion of recovered explosives and propellants to form other products.
Co-Firing in Boilers	Energetics are desensitized so that they can be co-fired with traditional fuels in commercial boilers for heat.
Wastestream treatment technologies (secondary wastestream treatment)	
Biodegradation, Aqueous/Slurry	Biodegradation process for the treatment of various wastestreams. Wastestreams include ammonium perchlorate contaminated wastewater, high explosive contaminated carbon, and wastestreams produced by base hydrolysis of energetic wastes.
Biodegradation, Composting	Energetics are degraded using a composting process. Used primarily for soil contaminated with significant quantities of energetics.
Oxidation, Ultraviolet	Oxidation of organic contaminants in water.
Enzyme Degradation	Use of enzymes to degrade explosive molecules in aqueous solution.

STEP 4. TECHNOLOGY SCREENS

Two initial screening criteria were applied to the identified technologies: (1) basic applicability of the technology to China Lake wastestreams, and (2) maturity of the technology. *Safety issues, especially those concerning significant handling and manipulation of wastes, will be addressed in Step 6 because the extent of handling and manipulation required has not been identified at this stage.*

OB, while listed as a “traditional method” in Table 3, is not considered a reasonable alternative to OD because it shares the most “undesirable” characteristic of OD: it produces the uncontrolled release of combustion products. OB is eliminated from further discussion in this report.

Basic Applicability Screen. Most of the alternatives to OD identified are being developed to treat the growing stockpile of unwanted munitions at demilitarization facilities. As a result, technology development is focused on production-scale demilitarization, which typically includes a large volume of a single type of munition. China Lake is an RDT&E facility, not a demilitarization facility. Our energetic wastestream is almost the exact opposite of that found at a typical demilitarization facility. China Lake generates and treats a relatively low volume but with a large and unpredictable variety of energetic wastes, while a typical demilitarization facility treats a high volume but with a small and predictable variety of energetic wastes.

This basic difference in energetic wastestreams makes technologies in the "disassembly" and "recovery and reuse" categories unsuitable for implementation at China Lake. Disassembly technologies typically involve assembly line operations, with preprogrammed machinery that repeats the same task. These processes are not appropriate for the relatively small volume and large variety of energetic wastes at China Lake. Recovery and reuse technologies require a relatively large, constant, and homogeneous energetic waste feedstock, which is recovered and reprocessed for sale or reuse. China Lake has a relatively small, sporadic, and heterogeneous energetic wastestream, making it unsuitable for recovery and reuse. Both the "disassembly" and "recovery and reuse" technology categories target production-scale demilitarization and are not appropriate for the relatively low volume and large variety of energetic wastestreams typical of an RDT&E facility such as China Lake. *Therefore, technologies in the disassembly and recovery and reuse categories are eliminated from further consideration in this paper.*

Technologies in the "removal" and "wastestream treatment" categories are considered ancillary (supplementary) treatments. These technologies would be coupled with a primary treatment technology, as either a pre-treatment of wastes ("removal") or a post-treatment of secondary wastestreams ("wastestream treatment"), respectively. Because the selection of these ancillary treatment technologies is dependent on the wastestream feed needs or secondary wastestreams generated by the primary treatment technology, *evaluation of the technologies in the removal and wastestream treatment categories is not included in this report.* It must be understood, however, that one or more of the removal and wastestream treatment technologies may be required if an alternative to OD technology is implemented. *It should be noted that OD does **not** require any pre- or post-treatment.*

In summary, technologies in the disassembly, recovery and reuse, removal, and wastestream treatment categories are eliminated from further evaluation in this report. Technologies in the disassembly and recovery and reuse categories are designed for production scale demilitarization and therefore are not considered practical for implementation at China Lake. Further evaluation of technologies in the removal and wastestream treatment categories is deferred because as ancillary treatments, the selection of a specific technology in either of these categories is dependent on the selection of the primary treatment method. Therefore, *the remainder of this report focuses only on evaluation of the primary treatment methods in the destruction category.* This summary is illustrated in Figure 4. The alternative treatment technologies remaining after this basic applicability screen are listed in Table 4.

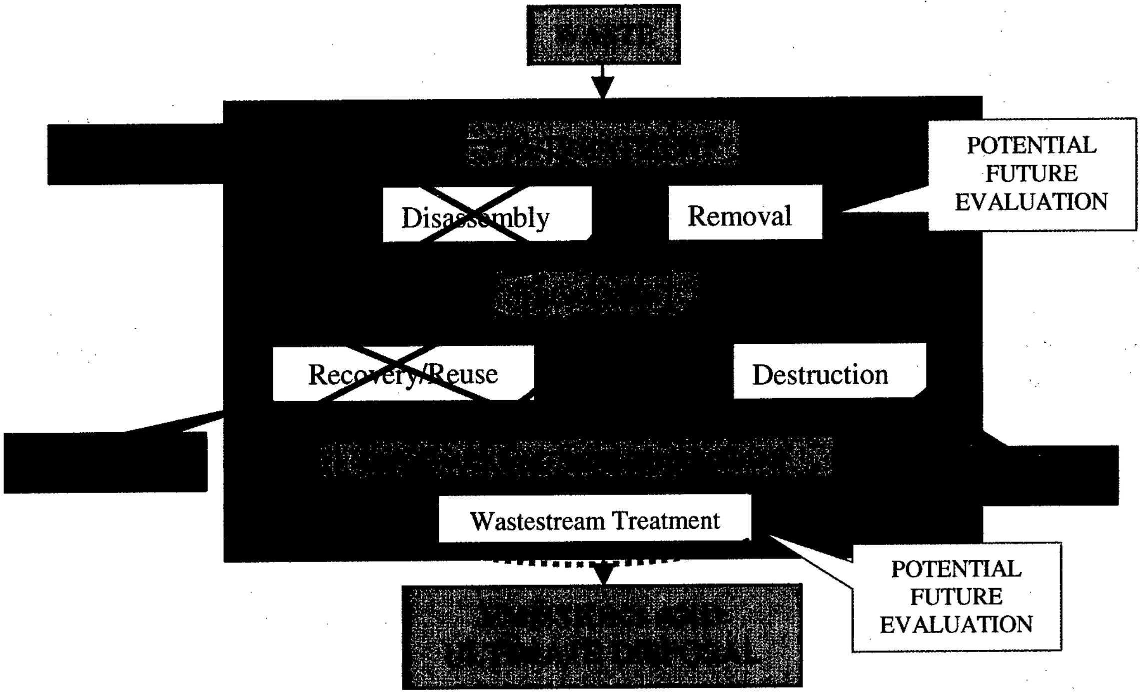


FIGURE 4. Summary of Basic Applicability Screening Results.

TABLE 4. Alternative Technologies Remaining After Basic Applicability Screen.

Open Detonation
Contained Detonation
Contained Burn #1, Solid Rocket Motors
Contained Burn #2, Confined Burn Facility
Contained Burn #3, Energetic Contaminated Wastes
Incineration, Rotary Kiln
Incineration, Plasma Arc
Incineration, Fluidized Bed
Oxidation, Base Hydrolysis
Oxidation, Supercritical Water (Hydrothermal Oxidation)
Oxidation, Molten Salt
Oxidation, Electrochemical
Oxidation, Peroxydisulfate
Oxidation, Adams Sulfur
Molten Metal
Oxidation, Wet Air
Hypergolic Non-Detonative Neutralization
Charged Particle Beam

Maturity Screen. The alternative technologies listed in Table 4 are at varying stages of development—ranging from conceptual ideas to commercially available. Technologies in very early stages of development, including those that are in the conceptual idea, feasibility study, or bench-scale stage, have been eliminated from the current evaluation because their degree of success and the potential for implementation cannot be reasonably predicted. If any of the technologies eliminated exhibit exceptionally promising results and are on an accelerated development schedule, they may be evaluated at a later date.

Table 5 summarizes the results of the maturity screen, with the basic applicability screen already applied. Table 6 lists the destruction technologies that will be the focus of the remainder of this report.

TABLE 5. Technology Maturity (Applicability Screen Already Applied).

Technology	Maturity
Destruction technologies	
Contained Detonation	G
Contained Burn #1, Solid Rocket Motors	G
Contained Burn #2, Confined Burn Facility	G
Contained Burn #3, Energetic Contaminated Wastes	G
Incineration, Rotary Kiln	G
Incineration, Plasma Arc	G
Incineration, Fluidized Bed	G
Oxidation, Base Hydrolysis	G
Oxidation, Supercritical Water (Hydrothermal Oxidation)	G
Oxidation, Molten Salt	G
Oxidation, Electrochemical	R
Oxidation, Peroxydisulfate	R
Oxidation, Adams Sulfur	R
Molten Metal	R
Oxidation, Wet Air	R
Hypergolic Non-Detonative Neutralization	R
Charged Particle Beam	R

Green:	**Advanced development or is in use, included for further evaluation.**
Red:	Conceptual, laboratory, or bench scale development for application to energetic wastes, eliminated from further evaluation at this time.

TABLE 6. Alternative Technologies Remaining After Initial Screening.

Contained Detonation
Contained Burn #1, Solid Rocket Motors
Contained Burn #2, Confined Burn Facility
Contained Burn #3, Energetic Contaminated Waste
Incineration, Rotary Kiln
Incineration, Plasma Arc
Incineration, Fluidized Bed
Oxidation, Base Hydrolysis
Oxidation, Supercritical Water (Hydrothermal Oxidation)
Oxidation, Molten Salt

STEP 5. REVIEW OF REMAINING ALTERNATIVE TECHNOLOGIES

This section provides current information on the technologies listed in Table 6. In addition to the technologies identified in Table 6, OD will be included as the baseline technology. A description of each technology is included.

The intent of these technology descriptions is to provide an overview of the technology, its developmental status, and a general understanding of how the technology fits into the treatment "lifecycle" of energetic wastes. Detailed qualitative and quantitative data are typically not provided because consistent data do not exist for the technologies. Available data vary significantly with the composition of the waste feed streams, throughput, operating conditions, and the use of scrubbing and filtration systems. Inclusion of these inconsistent data could mislead the reader into assuming that a qualitative and quantitative comparison of the technologies exists, when in fact it does not. An in-depth analysis, evaluation, and comparison of existing data for specific technologies would be required before a final decision to implement an alternative technology.

This lack of specific data is especially notable for process emissions. To appropriately compare emissions, the feed wastestreams must be consistent and the throughput, operating conditions, and scrubbing and filtration systems must be representative of full-scale operation. In addition, sampling and analysis methods must be consistent. A notable exception to excluding specific data in this report is the gross quantification of emissions for Contained Detonation as compared with OD. Because of the basic differences in the destruction processes (i.e., Contained Detonation suppresses after-burning; OD promotes after-burning with an abundance of oxygen) there are significant predictable and measured differences in the emissions. These gross differences are noted in the specific technology description for Contained Detonation.

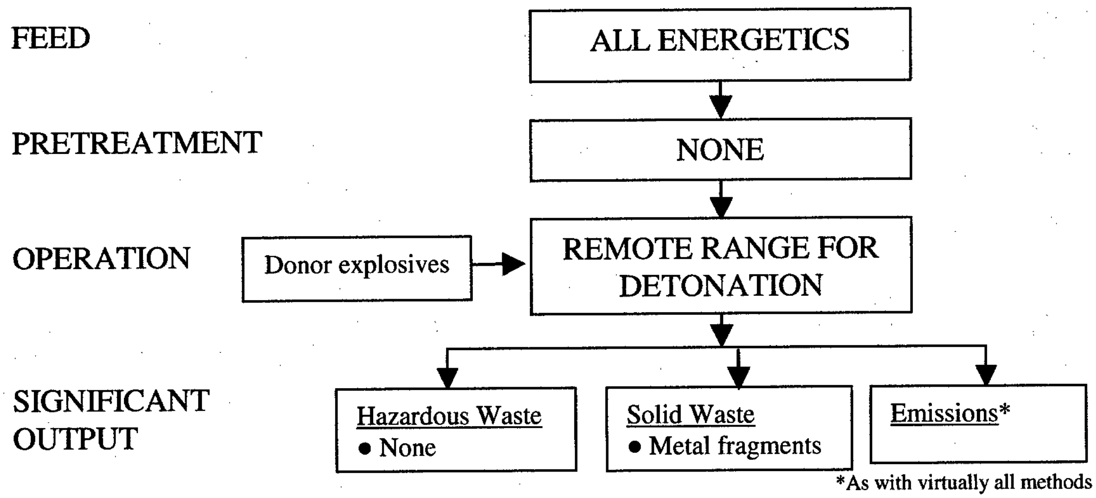
Each technology description consists of the following:

- Summary: Describes how the technology works.
- Flow chart: Generally shows how the integrated system would work. Includes:
    - General feed categories and limitations.
    - Generic pretreatments required.
    - System components and additional additives and resources required.
    - Generic outputs, including hazardous waste, solid waste, and emissions.
- Current Status: Describes current reported status of development or implementation of the technology.
- Capital costs: "Ball-park" estimate of capital costs.
- Future Plans: Reports future development or implementation plans.
- Developers and Users: Lists specific users, developers, or vendors of the technology.
- Applicability to China Lake wastes.

OPEN DETONATION

OD is the treatment of energetic wastes using an explosive donor charge to initiate the wastes to be detonated (see Figure 5). At China Lake the donor is typically Composition A3 or C4. The energetic wastes are carefully positioned, along with the donor charge, to ensure complete destruction of the wastes. The donor-to-waste ratio varies, depending on the type of waste that will be treated.

OD includes two major classes of reactions: the detonation and the after-burning. The detonation itself is a very rapid, very hot reaction that can reach thousands of °C and is over in microseconds. The detonation reaction may contain significant amounts of products that have not fully reacted. For example, there may be significant amounts of hydrogen and carbon monoxide gases. In the after-burning reactions that immediately follow the detonation, these intermediate products react with the air and are converted to final, stable products. For example, the carbon monoxide is converted to carbon dioxide and the hydrogen is converted to water. After-burning reactions typically have temperatures of 1,500 to 1,700°C and last for seconds. These after-burning reactions are very crucial in determining the final emissions, and anything that alters the after-burning will change the resulting emissions. For example, some facilities place large amounts of dirt over the detonation pile before initiating in order to suppress the blast and noise associated with OD treatment. While this practice does mitigate the blast and noise, it also suppresses the after-burning reactions, and some of the intermediate reaction products from the detonation are therefore not converted to stable final reaction products. Because products of incomplete combustion can pose some level of health risk, practices that suppress after-burning are avoided when possible.



*As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 5. Open Detonation.

Current Status

Current Method of Treatment of Energetic Wastes at China Lake. China Lake is in the process of assessing available data on OD emissions and obtaining additional data to ensure that a complete characterization of OD emissions is available.

Capital Costs

None.

Future Plans

China Lake plans to continue its compilation of OD emission data until a thorough characterization is available.

Developers and Users

Numerous DOD and commercial facilities, including China Lake, use OD as a treatment method for energetic wastes.

Applicability to China Lake Wastes

China Lake's entire energetic wastestream is currently treated using OD. OD requires minimal handling of altered and experimental energetics. The metal fragments resulting from the detonation of all metal cased munitions do not create a problem with OD.

CONTAINED DETONATION

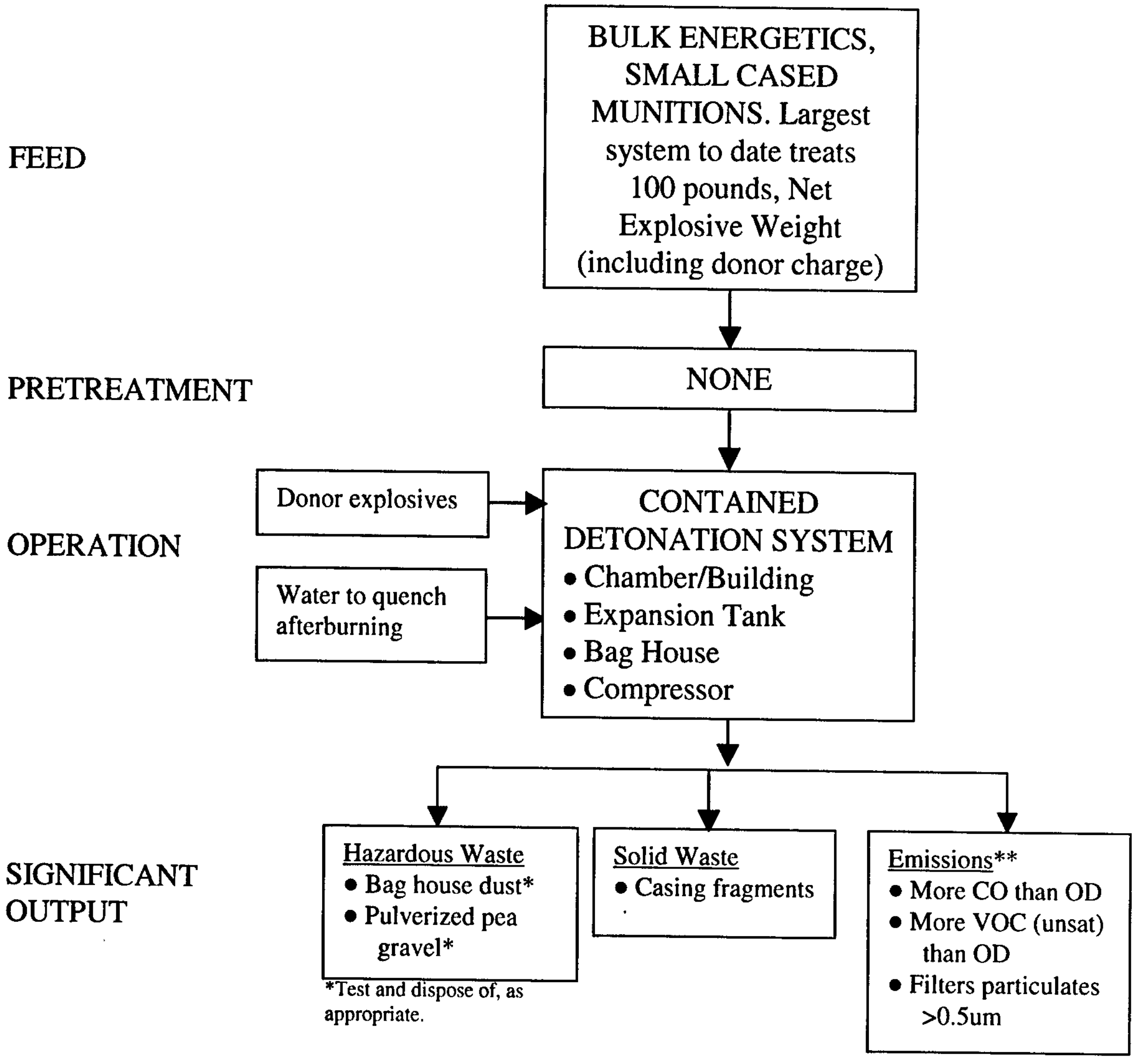
In Contained Detonation, uncased or lightly cased materials are placed into a reinforced chamber (see Figure 6). Water is suspended in plastic bags inside the chamber to reduce temperatures and blast energy (the water is vaporized during the process). Pea gravel covering the floor of the blast chamber helps to absorb some of the blast pressure. These processes help protect the integrity of the chamber. The chamber is closed and the materials are detonated. Emissions generated by the detonation are vented to an expansion chamber to reduce pressure and then to a baghouse system to filter out particulates down to 0.5 micrometer. The remaining emissions are vented to the air. Noise, overpressures, particulates greater than 0.5 micrometer, and thermal and debris hazards are reduced significantly. The water quenches the after-burning, which leads to an increase in products of incomplete combustion that may not be captured by the particulate filters. For example, the carbon monoxide to carbon dioxide reaction that normally occurs in the after-burning portion of the OD (conducted with ample air) is suppressed, resulting in significantly higher carbon monoxide emissions (Reference 6).

Current Status

An example of this technology is the "Donovan Blast Chamber."

Chambers range from 3- to 100-pound explosive (RDX equivalent) capacity. Air pollution control is a bag house that filters particulates down to 0.5 micrometer. All time "high" throughput was 100 detonations in a 10-hour period, while destroying M483A1 155mm projectiles (contains 88 submunitions). Destruction of fuzes; bursters; mine components; 105mm HE projectiles; 4.2-inch HE mortar rounds; 20mm, 40mm, and small arms ammunition; reactive chemicals; and bulk explosives was accomplished in the chamber. Donor explosives are always required and are included in the chamber limit. Donor to waste ratio can be as high as 1:1.

The D-100 chamber at Blue Grass Army Depot (Crane study, Reference 2) was used to detonate 45 pounds of bulk PETN as well as 105mm projectiles, 4.2-inch mortars, 25mm HEI-T, ignition cartridges, primers, boosters and expelling charges, and fuze and actuator for an M15 mine. During the study, leaks around bag house seals, drums, and the front door of the chamber and weld failures were experienced (October 2000). Problems will be fixed for the next phase of testing.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates (Reference 2).

FIGURE 6. Contained Detonation.

Capital Costs

$2.5 to $3.0 million is estimated for a complete D-100 system (100 pounds RDX net explosive weight).

Future Plans

Demil International, Inc., is designing a D-200 (200 pounds of RDX capacity) for Crane Navy Depot. Additional off-the-shelf pollution control devices could be adapted.

Developers and Users

Milan Army Ammunition Plant (MAAP), Milan, Tennessee. Two D-130s (now called D-100s) to destroy M483A1 155mm projectiles and all of the submunitions. 25,000 projectiles destroyed July 1997 to December 1998.

Camp Edwards, Massachusetts Military Reservation. Uses T-10 chamber. The T-10 chamber can handle two 81mm high-explosive mortar rounds, for a total of 13 pounds of net explosives. As of April 2001, 1,700 items had been detonated. These items include 60- and 81mm mortars; 2.36- and 3.5-inch rockets; 30-, 37-, 57- and 75mm projectiles; rifle grenades; and fuzes. Typical mass ratio of donor explosive to ordnance item explosive is 1:1.

Naval Surface Warfare Center, Crane Division; Keith Sims. Crane is leading a study of the contained detonation chambers. As part of this study a D-100 chamber has been installed at Blue Grass Army Depot, Lexington, Kentucky. This unit has demonstrated the ability to contain overpressures/noise/particulate emissions up to 35 pounds and shrapnel from 105mm high explosive (HE) projectiles, 4.2-inch cartridges, and miscellaneous detonators and fuzes. In the evaluation by Crane, leaks around bag house seals, drums, and the front door of the chamber and weld failures were experienced (October 2000).

Demil International, Inc.; Kenneth House (Vice President), 221 East Side Square, Huntsville, Alabama 35801; e-mail: kenhouse@demil.net. This company manufactures contained detonation chambers. The smallest chamber is a portable, 30-ft^3 unit with 7 pounds of TNT equivalent capacity. The largest chamber provides 130 pounds of TNT equivalent capacity.

Blue Grass Army Depot; Joel Kallenberger. Blue Grass Army Depot has the chamber that Crane is studying. The chamber has contained overpressures/noise/particulate emissions up to 35 pounds and shrapnel from 105mm HE projectiles and 4.2-inch cartridges. Claims to have the chamber with the largest explosive capacity constructed to date.

Applicability to China Lake Wastes

Potential to treat 42 to 54% of China Lake's wastes.

Bulk Energetics. Contained detonation has the potential to treat most of the wastes in this category. If the waste is a large block of energetic materials, the block would have to be cut down into smaller blocks, which could be a problem given the sometimes unknown and unpredictable nature of China Lake's energetic wastestream. In addition, there may be a problem with treatment of some propellants (see no. 3 under "General Comments," below).

Small Cased Munitions. Contained detonation has the potential to treat most of the wastes in this category. Munitions with a significant amount of casing metal, which would fragment during detonation and damage the walls of the chamber, would significantly increase the maintenance and decrease the life of the unit.

Medium Cased Munitions. Contained detonation has the potential to treat some of the wastes in this category. Although the amount varies, many of the munitions in this category are close to 100 pounds per item. Currently, the largest contained detonation chamber can only accommodate up to 100 pounds of RDX equivalent, *total* (munitions plus donor). Assuming a 1:1 waste energetic to donor ratio would limit the waste munitions to 50 pounds. Munitions with a significant amount of metal casing, which would fragment during detonation, would significantly increase the maintenance and decrease the life of the unit. Fragments created by the detonation of munitions with thick metal casings would probably destroy the chamber. In addition, there may be a problem with treatment of propellants (see no. 3 under "General Comments," below).

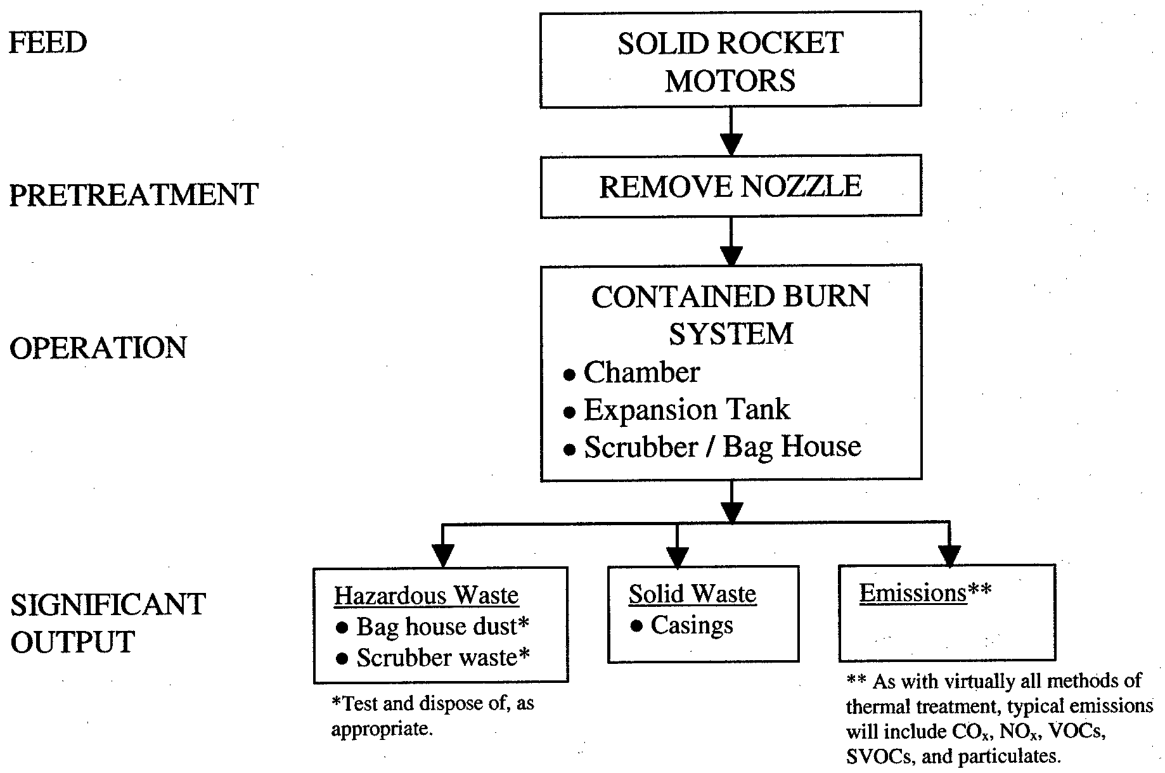
Large Cased Munitions. Contained detonation is not appropriate for wastes in this category. These items contain more energetic material than existing chambers can handle. In addition, fragments created by the detonation of munitions with thick metal casings would destroy the chamber.

General Comments

1. Currently, the only effluent treatment this technology has incorporated is the filtration of particulates.
2. Suppression of the after-burning reaction would lead to significantly more products of incomplete combustion, such as carbon monoxide (CO) instead of carbon dioxide (CO_2).
3. Hydrogen chloride gas is produced in the detonation of propellants containing ammonium perchlorate. Hydrogen chloride is very corrosive, especially at high temperatures, and would attack the system walls and other surfaces, and would also be released through the exhaust system.
4. Significantly more handling would be required to treat China Lake's wastestream. The D-100 unit would require between 20 and 90 handling evolutions compared to one OD event.

CONTAINED BURN #1, SOLID ROCKET MOTORS

This technology involves burning rocket motors at very low pressures, without nozzles, into a confined chamber (see Figure 7). Emissions are collected and then processed through a series of quenching and scrubbing chambers to remove particulates, acid gases, and organic contaminants.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 7. Contained Burn #1, Solid Rocket Motor.

Current Status

Two facilities were developed and demonstrated at China Lake: the Modified Contained Burn Assessment Test (MCBAT) facility for strategic rocket motors, and the Tactical Demilitarization Test facility for the lead-containing Shillelagh rocket motor and for composite propellant rocket motors. This capability was demonstrated on three types of rocket motors: a large rocket motor containing 17,450 pounds of Class 1.1 hazard classification propellant (mass detonating), a lead-containing rocket motor with 11 pounds of propellant, and an ammonium-perchlorate-containing rocket motor with 60 pounds of propellant. Two separate filtration systems were developed and demonstrated, one to separate out the heavy metals (lead) and one to neutralize the hydrochloric acid produced by the ammonium perchlorate.

Capital Costs

Approximately $100 million was spent on the development and demonstration of the large rocket motor contained burn demonstration.

Future Plans

We are working on a large rocket motor treatment system for Russia's Cooperative Threat Reduction Program through the Defense Threat Reduction Agency. Production rate development and demonstration are under way at the Nevada Test Site for the system that treats energetics with heavy metals.

Developers and Users

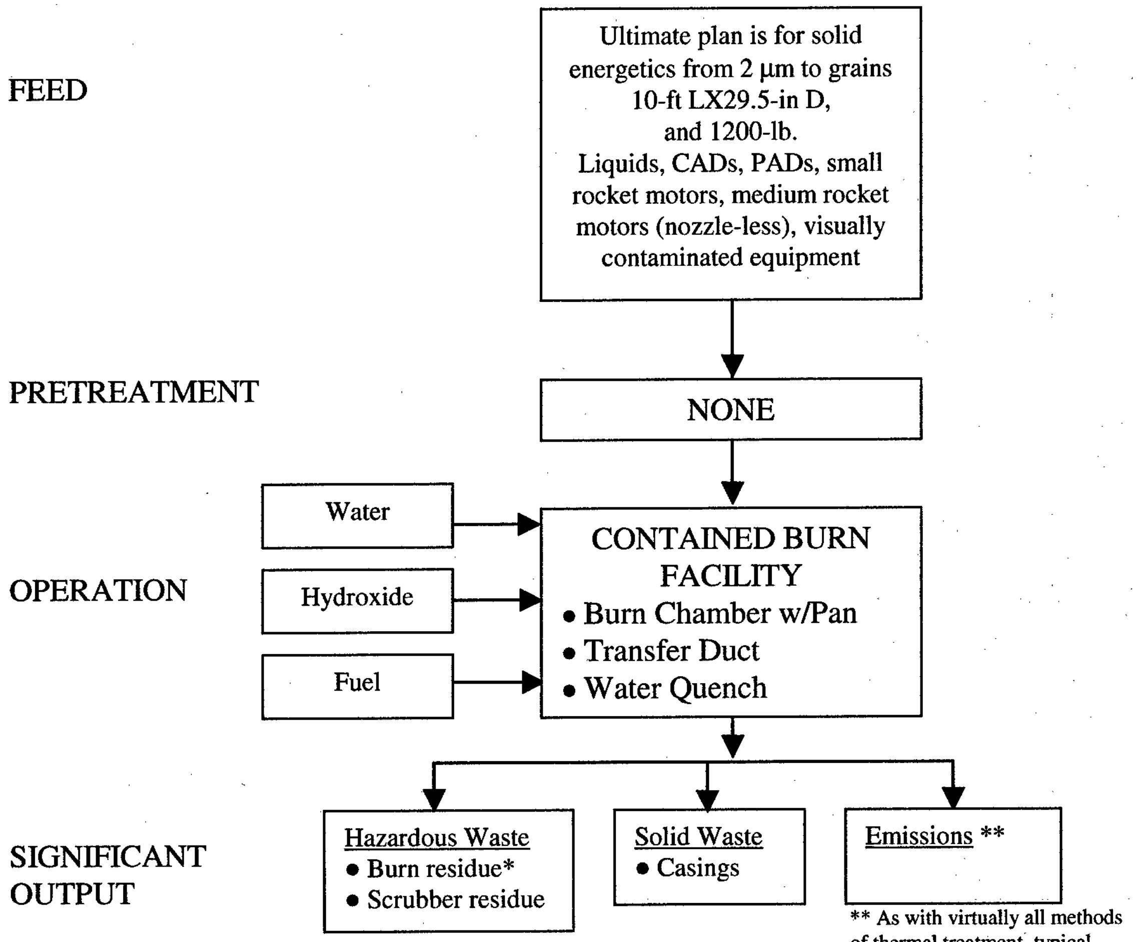
A team of Naval Air Warfare Center Weapons Division (NAWCWD) China Lake, POC: Terry AtienzaMoore; Lockheed Martin Missiles and Space, Advanced Technology Center (LMMS-ATC); and Bechtel Corporation developed and demonstrated this technology.

Applicability to China Lake Wastes

This technology was designed primarily for the demilitarization of large, strategic rocket motors. The percentage of China Lake's waste has not been determined. Tailoring this technology for rocket motors generated from RDT&E activities would require redesign. This technology is more suitable to demilitarization activities.

CONTAINED BURN #2, CONFINED BURN FACILITY

This technology involves burning waste in a chamber (see Figure 8). The chamber is designed to contain an unintentional detonation. Emissions are contained, treated using conventional pollution control equipment, and released to the atmosphere.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 8. Contained Burn #2, Confined Burn Facility.

Current Status

A pilot-scale contained burn facility study was completed with 10-pound batches.

Capital Costs

To be determined. This project is in the developmental stage, but the current estimate for the Indian Head Division, Naval Surface Warfare Center (NSWC) system, with 3- to 1,200-pound burn chambers and a central scrubbing unit is $18.4 million.

Future Plans

Indian Head Division, NSWC is currently planning 80-pound batches, or up to 20 pounds per hour under an Environmental Securities Technology Certification Program project. The ultimate goal is to treat in 1,000-pound batches of Class 1.1 hazard classification propellant or 1,200-pound batches of Class 1.3, with a rate of up to 750 pounds per hour. Planned start-up of the full-scale system is fiscal year 2007.

Developers and Users

Indian Head Division, NSWC. Tim Brennan, Code 2150J, Indian Head, Maryland.

Applicability to China Lake Wastes

Potential to treat 42% of China Lake's wastes.

Bulk Energetics. Contained burn has the potential to treat most of the wastes in this category. However, development and demonstration of full-scale treatment must be completed. Experience with open burn pans has shown that there is significant potential for the transition to detonation when burning large quantities of propellants.

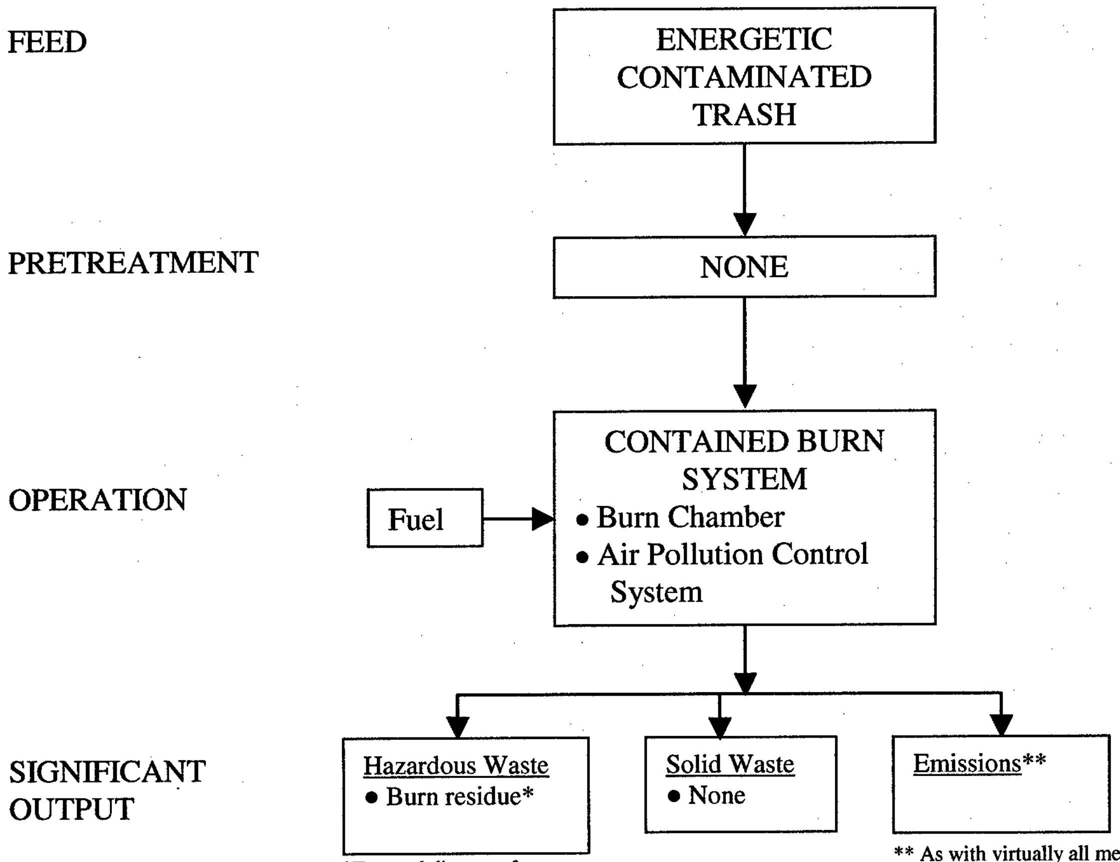
Small Cased Munitions. Contained burn has the potential to treat most of the wastes in this category. Although the items would detonate rather than burn, the munitions in this category are small enough and the contained burn system should be robust enough to handle it. Munitions with a significant amount of metal casing, which would fragment during detonation, would significantly increase the maintenance and decrease the life of the unit.

Medium Cased Munitions. Contained burn is not appropriate for wastes in this category. The munitions would detonate, and the items in this category are large enough to cause significant damage to the chamber.

Large Cased Munitions. Contained detonation is not appropriate for wastes in this category. The items would detonate and cause significant damage to the chamber.

CONTAINED BURN #3, ENERGETIC CONTAMINATED WASTES

This technology is similar to the Contained Burn Facility previously described but is more applicable to energetic-contaminated waste such as rags, gloves, wipes, etc. (see Figure 9). Additional fuel may be used to initiate or sustain combustion. Emissions may or may not be vented through air pollution control equipment.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 9. Contained Burn #3, Energetic Contaminated Waste.

Current Status

Commercially available.

Capital Costs

To be determined.

Future Plans

None identified at this time.

Developers and Users

El Dorado Engineering, Inc. Salt Lake City, Utah, mail@eldoradoengineering.com. This technology offers a 7- by 8.5- by 21.5-foot Contaminated Waste Processor (CWP) unit that can handle 600 pounds per hour of combustible waste and a 6- by 7- by 13-foot unit that can handle 300 pounds per hour of combustible waste.

Pine Bluff Arsenal. This facility has a "Chain Grate Furnace" used to flash/decontaminate metal, wood, cardboard, paper, etc. They also have a "Car Bottom Furnace" that is similar to the Chain Grate Furnace, but is also capable of handling colored smoke mixes.

Iowa Army Ammunition Plant. Uses a Contaminated Waste Processor.

Blue Grass AD. Uses a Contaminated Waste Processor.

Savanna ADA. Uses a Contaminated Waste Processor.

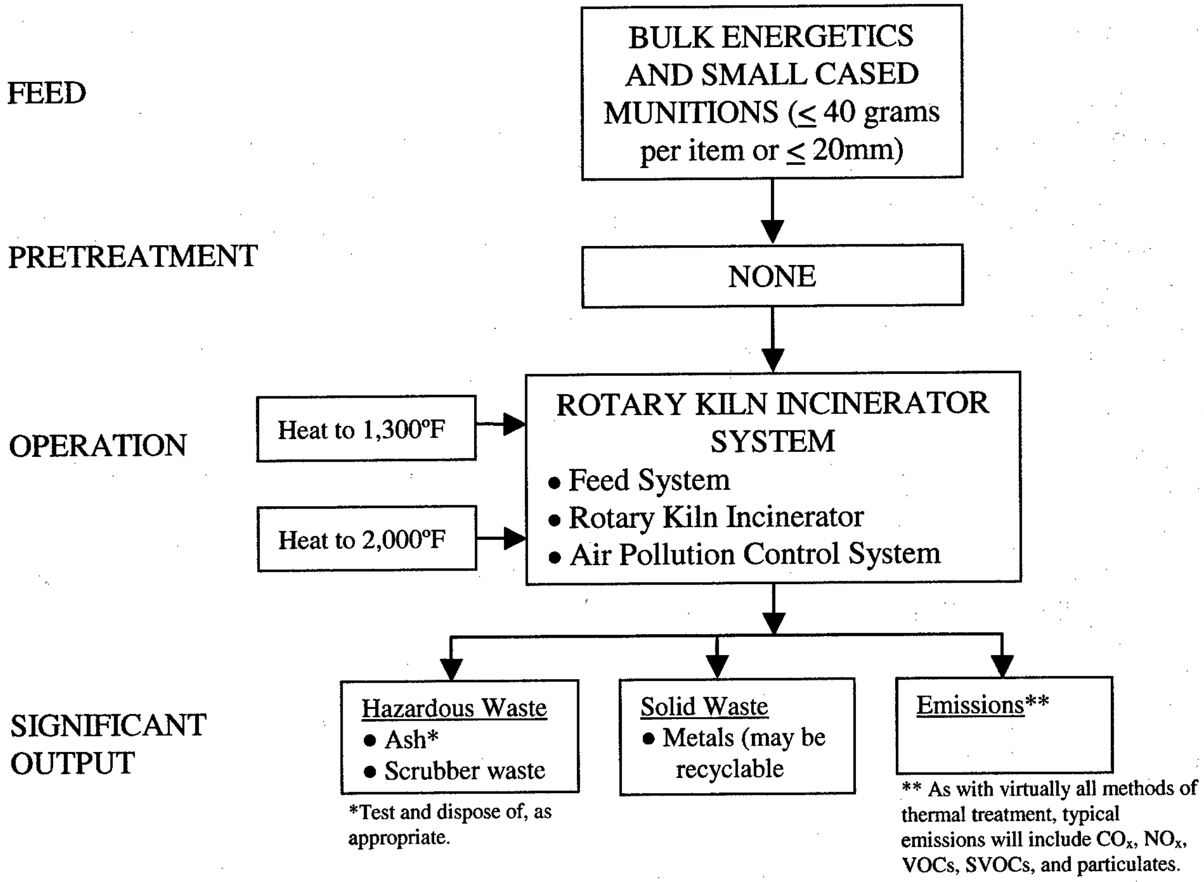
Applicability to China Lake Wastes

This technology can only treat combustible trash contaminated with small quantities of energetic materials. It has the potential to treat a small portion of China Lake's wastes in the bulk energetics category (< 37%).

INCINERATION, ROTARY KILN

Waste is fed into the rotary kiln through either a continuous or positive feed system (See Figure 10). The rotary kiln rotates, slowly moving the waste from one end to the other. The waste detonates or combusts, becomes part of the flue gas that leaves the kiln, and goes to the secondary combustion chamber. From the secondary combustion chamber, the flue gas is "quenched." The gas is then typically scrubbed and filtered through a bag house before it is discharged.

The rotary "Deact" furnace is also considered a rotary kiln. The Deact furnace is a modified APE 1236 furnace and is designed to handle grenades, fuzes, and cut up hardware from pyrotechnics, white phosphorous, riot control devices, colored smoke munitions, and small explosive items.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 10. Incineration, Rotary Kiln.

Current Status

This technology is considered to be mature for small arms ammunition, small munitions, and bulk energetics. It is capable of processing up to ~40 grams of confined explosives per item. ICIEE, Joplin, Missouri, operates a permitted commercial rotary kiln incinerator. Several Army bases also operate rotary kiln incinerators. Some have recently been or are now in need of retrofitting to changing air pollution control requirements.

Capital Costs

$3 million.

Future Plans

None identified at this time.

Developers and Users

ICIEE, Joplin, Missouri. Operates a permitted commercial hazardous waste incinerator.

Tooele Army Depot. Uses an APE 1236M1 Deactivation Furnace / Explosive Waste Incinerator.

Lake City Army Ammunition Plant (LCAAP), Missouri. This unit is permitted to burn primers and fuzes containing heavy metals. Incinerates off-specification primers from production of small caliber ammunition.

Iowa Army Ammunition Plant (IAAP), Iowa. Latest status is that the unit is shut down while awaiting funding for upgrades and trial burn.

Pine Bluff Arsenal. This system is used to treat colored smokes, CS/HC (smoke) canisters, grenades, cartridges, and various fuzes/bursters.

Applicability to China Lake Wastes

Potential to treat 42% of China Lake's wastes.

Bulk Energetics. Rotary kiln incineration has the potential to treat most of the wastes in this category. If the waste consists of a large block of energetic material, its size may need to be decreased into 5-pound blocks to prevent detonation. This pretreatment process may be dangerous given the sometimes unknown and unpredictable nature of China Lake's energetic wastestream.

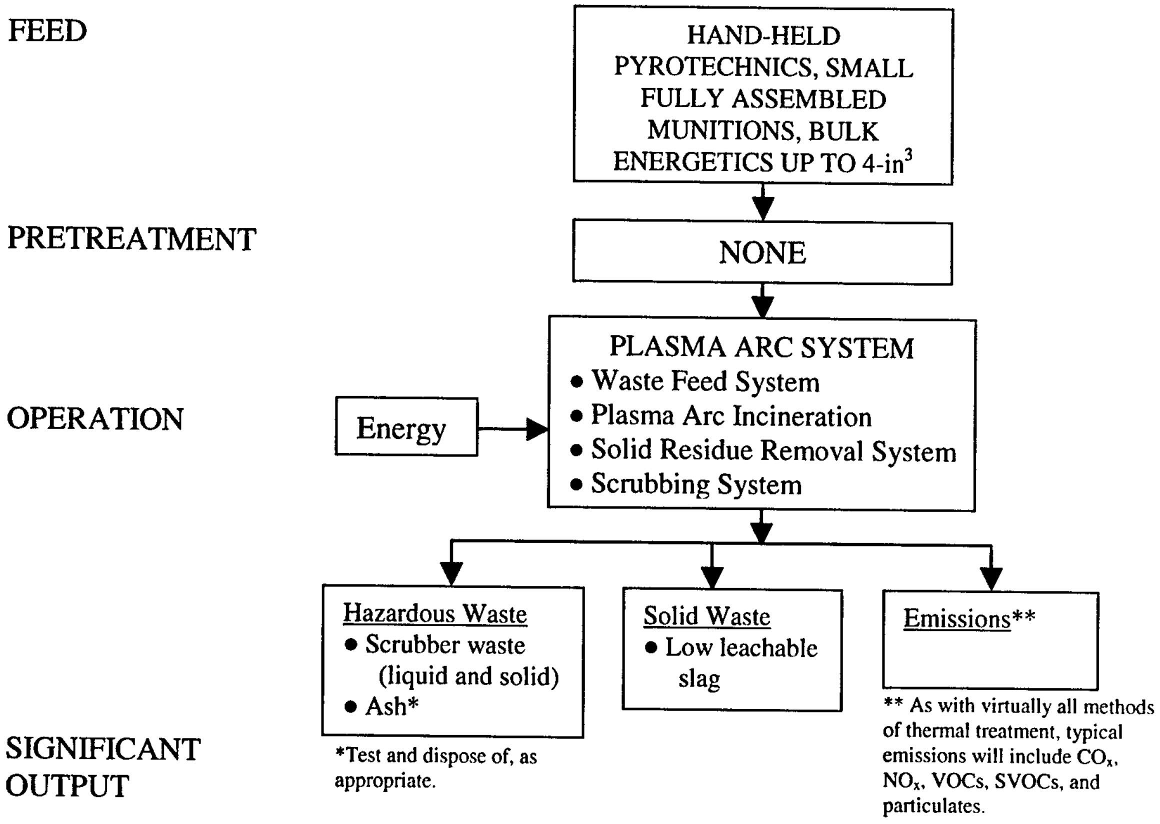
Small Cased Munitions. Rotary kiln incineration has the potential to treat most of the wastes in this category. Munitions with a significant amount of metal casing, which would fragment during detonation, would increase the maintenance of the unit.

Medium Cased Munitions. Rotary kiln incineration is not appropriate for wastes in this category.

Large Cased Munitions. Rotary kiln incineration is not appropriate for wastes in this category.

INCINERATION, PLASMA ARC

Soil (with iron as the fluxing agent) is fed into the plasma furnace along with waste energetics to create a molten slag pool (see Figure 11). This pool destroys organic compounds and traps non-volatile inorganic compounds including heavy metals. The hardened slag has minimal leaching characteristics and can typically be disposed of as a non-hazardous waste. Organic compounds are rapidly destroyed via oxidation, with the products leaving the furnace as gases. Gases are scrubbed before being released to the atmosphere.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 11. Incineration, Plasma Arc.

Current Status

In a test for treating range residue, the Mobile Plasma Treatment System (MPTS) processed a total of 800 bullet tips (2000 pounds, 3 inches at the base and 4.5 inches long) through the initial testing of the unit, with over 50 hours of plasma arc torch operation completed. Design, procurement, and fabrication of an optimized 500-pound-per-hour system has been completed.

Capital Costs

Rough estimate between $3 and 12 million in capital costs, depending on the size, nature of waste, and complexity of the treatment process.

Future Plans

MSE Technology Applications, Inc., has fabricated a 500-pound-per-hour prototype system for installation at Hawthorne, Nevada. Start-up of the facility is expected during 2003.

Developers and Users

Plasma Energy Application Technology (PEAT), Huntsville, Alabama.

MSE Technology Applications, Inc. Fabricated an MPTS.

USACERL/Environmental Processes Branch (CN-E), Ed Smith, e-smith@cecer.army.mil. A paper, "Plasma Arc Technology Applications for the Treatment and Recycling of Range Scrap Wastestreams," was presented at the *2001 Global Demilitarization Symposium and Exhibition* (Reference 4).

Applicability to China Lake Wastes

Potential to treat 42% of China Lake's wastes.

Bulk Energetics. Plasma arc incineration has the potential to treat most of the wastes in this category. If the waste consists of a large block of energetic material, its size may need to be decreased into smaller blocks to prevent detonation. This pretreatment process would be dangerous given the sometimes unknown and unpredictable nature of China Lake's energetic wastestream.

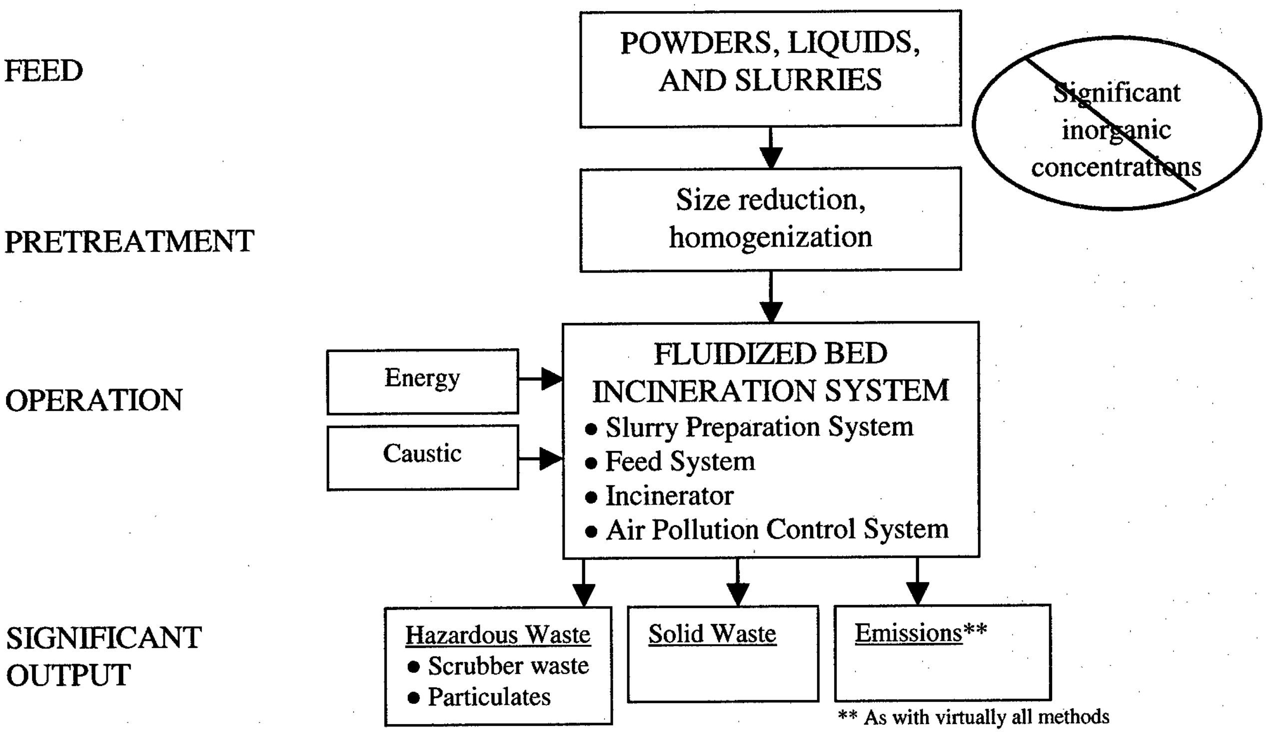
Small Cased Munitions. Plasma arc incineration has the potential to treat most of the wastes in this category. Munitions with a significant amount of metal casing, which would fragment during detonation, would significantly increase the maintenance and decrease the life of the unit.

Medium Cased Munitions. Plasma arc incineration is not appropriate for wastes in this category.

Large Cased Munitions. Plasma arc incineration is not appropriate for wastes in this category.

INCINERATION, FLUIDIZED BED

The Fluidized Bed Incinerator is enclosed and uses forced air to create a turbulent bed of sand (Figure 12). The sand is heated to 2,000°F. Energetic wastes are fed into the incinerator as powders, liquids, and/or slurries. Combustion emissions pass through a centrifugal separator for removal of large particulates (> 8 micrometers), to a gas quench tower and a variable throat wet venturi scrubber for removal of acid gases and fine particulates prior to discharge into the atmosphere. The scrubber effluent is discharged to a central waste treatment facility, where it undergoes pH stabilization and removal of dissolved solids prior to release to the environment.



*Test and dispose of, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 12. Incineration, Fluidized Bed.

Current Status

Pine Bluff Arsenal operates a Fluid Bed Incinerator in their Incineration Complex. It treats up to 180 gallons per hour (Reference 5, 1995 update).

The FOI Swedish Defense Research Establishment has conducted simulations and some trial runs (Reference 4).

Capital Costs

To be determined.

Future Plans

None identified at this time.

Developers and Users

Pine Bluff Arsenal.

Applicability to China Lake Wastes

Potential to treat less than 37% of China Lake's waste.

Bulk Energetics. This technology is only applicable to a portion of the bulk energetics category. The applicability is further limited and complicated by its inability to efficiently handle wastes with significant inorganic components. In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry is difficult and potentially dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would occur during this type of pretreatment.

Small Cased Munitions. Fluidized bed incineration is not appropriate for waste in this category.

Medium Cased Munitions. Fluidized bed incineration is not appropriate for waste in this category.

Large Cased Munitions. Fluidized bed incineration is not appropriate for waste in this category.

OXIDATION, BASE HYDROLYSIS

This system converts energetic wastes into water-soluble, non-energetic products (Figure 13). Energetic wastes are heated to mild temperatures (90 to 150°C) and often elevated pressure (up to 200 psig) with a strong base (sodium hydroxide or ammonia solution with pH > 12). Size reduction is typically required to treat bulk energetics. The greater the surface area exposed to the caustic solution, the faster and more efficient the process will be. This process decomposes the energetic waste to a water-soluble product. The product is toxic and corrosive and requires further treatment.

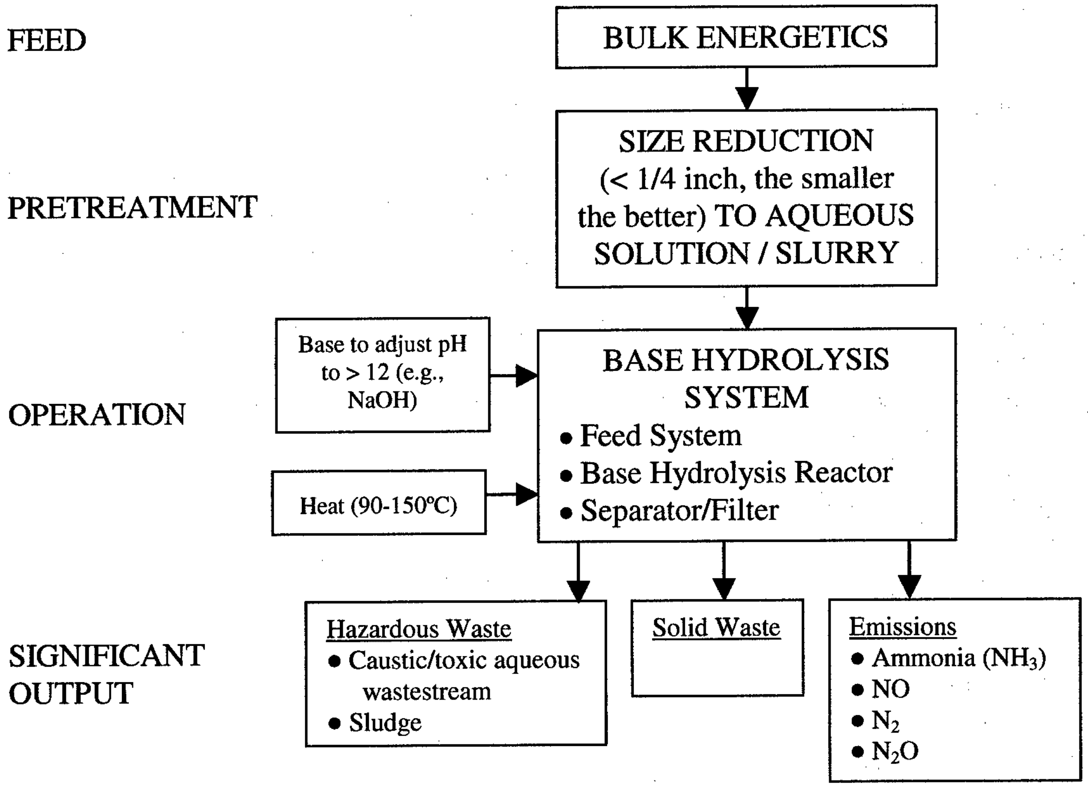


FIGURE 13. Oxidation, Base Hydrolysis.

Current Status

Development is currently focused on using base hydrolysis as a pretreatment for SCWO. Chemical weapons are the targeted wastestream.

BAE Systems, Royal Ordnance North America, Inc., Holston Army Ammunition Plant, Kingsport, Tennessee, constructed and tested a 2,000-gallon hydrolysis reactor pilot plant. Feed rates were tested up to 250 pounds per hour (a total of 500 pounds of energetic feed was treated in a 4-hour feed cycle with a 6-hour digestion period). Tetrytol, Comp B, Comp B4, M28 propellant, M8 propellant, and M1 propellant were all tested.

Capital Costs

To be determined: still developmental.

Future Plans

This technology is being proposed as a pretreatment for many of the treatment trains being investigated for the Assembled Chemical Weapons Assessment.

Developers and Users

Air Force Research Laboratory Propulsion Directorate, Edwards Air Force Base. A base hydrolysis system was constructed and is being tested to treat Class 1.3 hazard classification propellant waste from R&D activities. The waste is processed through a shredder to reduce the size of the bulk energetic and non-energetic materials. The batch process is designed to treat up to 100 pounds of propellant waste per batch in a 300-gallon reactor. Digestion time is estimated to be 1 to 3 days per batch. Additional development of the system is currently on hold pending further investigation.

United Technologies Corporation. This facility uses a water jet process to cut energetic contaminated debris into dime-sized pieces. Base hydrolysis technology is then used to render the wastestream non-energetic. All treated energetic waste is then transported to an off-site treatment facility. Operation and maintenance costs are estimated at $25 per pound, primarily due to the treatment of wastewater from the water jet and the spent hydroxide solution.

DOE Pantex Plant, Amarillo, Texas. 200-gallon scale hydrolysis experiments of HMX-based explosives. Generated hydrolysates (hydrolyzed energetics) from energetics Comp B and Tetrytol for Assembled Chemical Weapons Assessment Program (ACWA) demonstrations.

Radford Army Ammunition Depot, Radford, Virginia. Generated hydrolysates from energetics M28 propellant for ACWA demonstrations.

Los Alamos National Laboratory. Uses a small bench-top unit, as well as 55-gallon pilot-scale reactor for R&D.

BAE Systems, Royal Ordnance North America, Inc., Holston Army Ammunition Plant, Kingsport, Tennessee, Michael J. Ervin. A paper presented at the *2001 Global Demil Conference* (Reference 7). Constructed and tested a 2,000-gallon hydrolysis reactor pilot plant for ACWA.

Applicability to China Lake Wastes:

Potential to treat less than 37% of China Lake's wastes.

Bulk Energetics. This technology is only applicable to a portion of the bulk energetics category. The applicability is further limited and complicated by its difficulty with treating energetics that have been prepared with hydroxyl terminated polybutadiene (HTPB) binder (Reference 8; HTPB is a very common fuel/binder used for rocket propellants and explosives). In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would occur during this type of pretreatment.

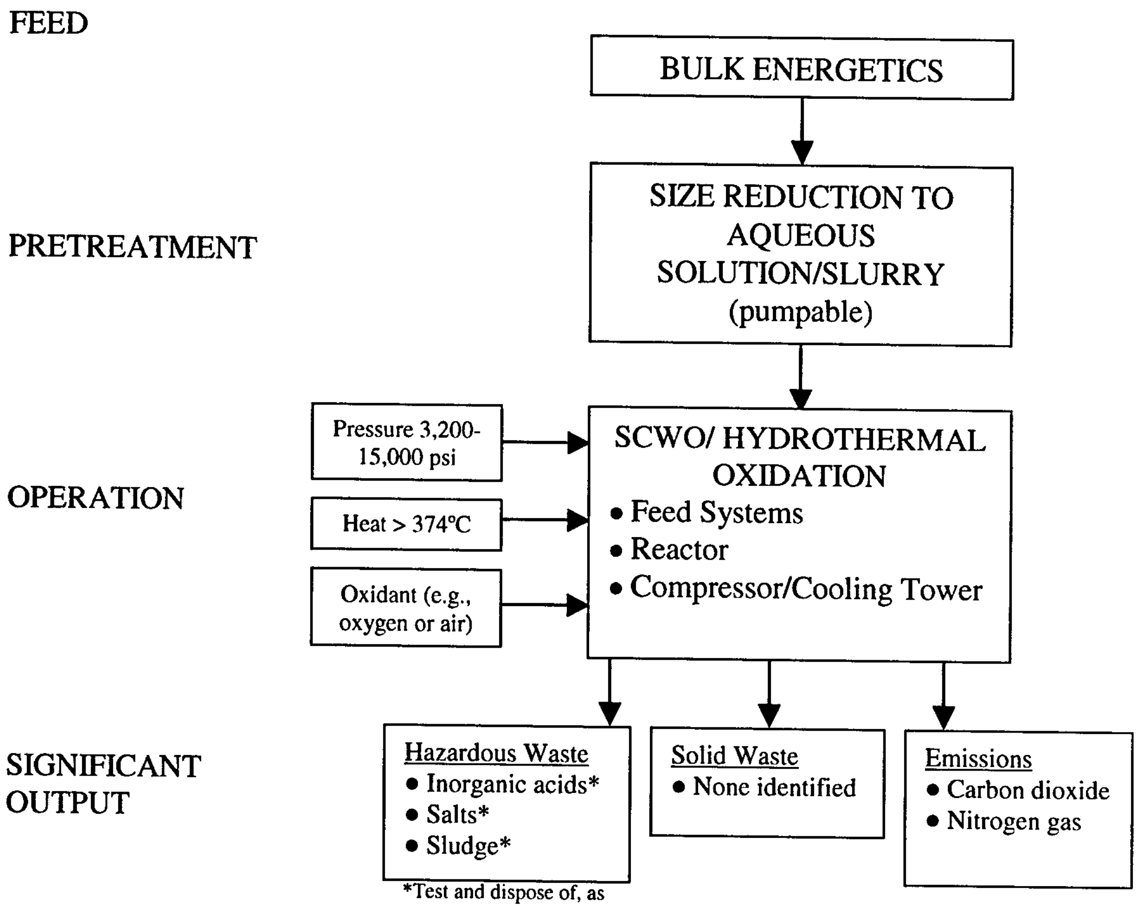
Small Cased Munitions. Base hydrolysis oxidation is not appropriate for wastes in this category.

Medium Cased Munitions. Base hydrolysis oxidation is not appropriate for wastes in this category.

Large Cased Munitions. Base hydrolysis oxidation is not appropriate for wastes in this category.

OXIDATION, SUPER CRITICAL WATER (HYDROTHERMAL OXIDATION)

This process involves subjecting the organic waste, water, and an oxidant (such as air or oxygen) to temperatures and pressures above the critical point of water (374°C, 3,200 psig). In many cases, the technology is being developed as a wastestream treatment method, and is used to treat hydrolysate product from a base hydrolysis process (see Figure 14).



*Test and dispose of, as appropriate.

FIGURE 14. Oxidation, Super Critical Water.

Current Status

Sandia National Laboratories, Livermore, uses a 325-cubic-centimeter SCWO laboratory setup to test batch process feasibility. A 1.5-liter (L) prototype unit for their "advanced batch SCWO reactor" concept is also used for R&D of this technology. The SCWO technology is currently focused on chemical weapons destruction.

The Army is working on implementing a prototype unit at Pine Bluff Arsenal. Wastestream focus is on colored smokes and dyes. They will use a new reactor design based on GenCorp Aerojet's transpiring wall platelet technology, which may protect the reactor from salt deposition and corrosion. The system is still undergoing major debugging.

General Atomics has demonstrated the destruction of TNT-contaminated wastewater ("pink water") in a prototype unit. Capacity is 1.2 gallons per minute and has operated at full capacity for 2 hours. The testing claims a 99.999% destruction efficiency for total organic carbon (TOC).

Capital Costs

To be determined: still developmental.

Future Plans

The start-up of an 80-pound-per-hour SCWO prototype unit at Pine Bluff Arsenal.

Developers and Users

Foster Wheeler. Developing a "transpiring wall reactor" that is supposed to control corrosion and salt plugging on a long-term, continuous basis.

General Atomics, James Elliot.

Sandia National Laboratory, Livermore, California. Uses a bench scale 10-gallon-per-day unit.

Applicability to China Lake Wastes

Potential to treat less than 37% of China Lake's wastes.

Bulk Energetics. This technology is only applicable to a portion of the bulk energetics category. In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would occur during this type of pretreatment.

Small Cased Munitions. Hydrothermal oxidation is not appropriate for wastes in this category.

Medium Cased Munitions. Hydrothermal oxidation is not appropriate for wastes in this category.

Large Cased Munitions. Hydrothermal oxidation is not appropriate for wastes in this category.

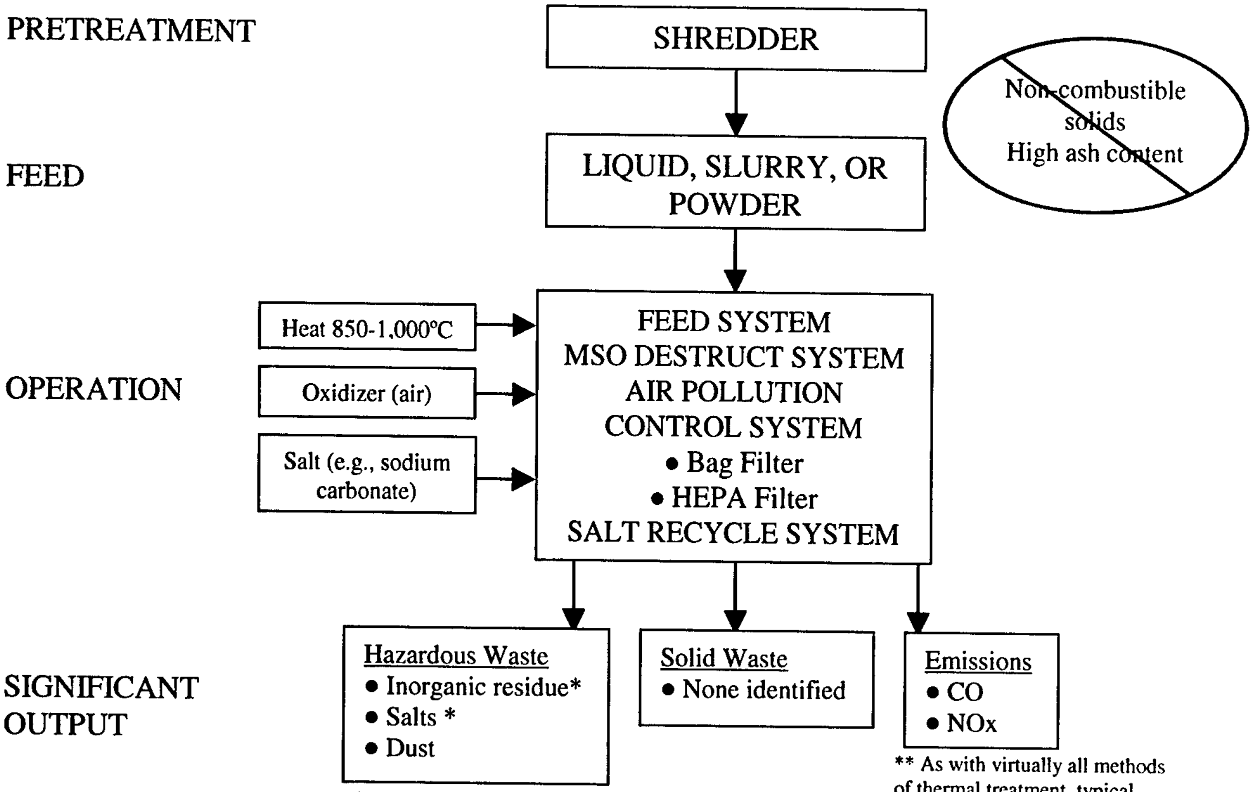
OXIDATION, MOLTEN SALT

Air and energetic waste are injected into a molten salt bed (e.g., sodium carbonate or potassium carbonate). The organic wastes react with the air in the molten salt to form carbon dioxide and steam. The product emissions are forced to pass through the molten salt before exiting the unit, resulting in good retention of metals and acid gases. The operating temperatures are typically between 850 and 1,000°C. The treatment process is applicable to bulk energetics, colored smoke munitions, and dyes. A uniform feed provides the most effective and efficient treatment, so pretreatment, such as shredding, is usually required to make the feed homogenous (see Figure 15).

Current Status

NSWC Indian Head Division is developing Molten Salt Oxidation (MSO). Comp A, Comp B, Comp C, and Double Base propellants have been treated. The maximum feed rate demonstrated to date for energetics is 5 pounds per hour. At feed rates over 1.5 pounds per hour, hydrocarbons are detected in the emissions.

Lawrence Livermore National Laboratory (LLNL) is developing an MSO system for the destruction of explosives sludge and explosive-contaminated activated carbon for a U.S. Army facility in the Republic of Korea. During earlier development, tests were conducted with RDX, HMX, TNT, Explosive D, and Comp B3. The maximum feed rate was 1.8 kilograms per hour with RDX. One of the units that LLNL constructed was transitioned to Eglin AFB for additional testing.



*Test and dispose of or recycle, as appropriate.

** As with virtually all methods of thermal treatment, typical emissions will include CO_x, NO_x, VOCs, SVOCs, and particulates.

FIGURE 15. Oxidation, Molten Salt.

Capital Costs

To be determined; still developmental.

Future Plans

Indian Head plans to scale up to a 36-inch-diameter reaction vessel for a full-scale demonstration after they have tested and evaluated their 12-inch-diameter prototype vessel.

LLNL plans to increase their processing rate to 30 kilograms per hour in 2003.

Developers and Users

Naval Surface Warfare Center, Indian Head Division, Jerry Salan, Mark Heslop. Uses a 12-inch prototype MSO treatment vessel.

LLNL, Dr. Peter C. Hsu.

Air Force Research Laboratory, Eglin Air Force Base, Donald Littrell. Developing a pilot-scale MSO facility to demonstrate the destruction of a variety of explosive/water slurries.

Applicability to China Lake Wastes

Potential to treat less than 37% of China Lake's wastes.

Bulk Energetics. This technology is only applicable to a portion of the bulk energetics category. In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry or powder is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would occur with this type of pretreatment.

Small Cased Munitions. MSO is not appropriate for wastes in this category.

Medium Cased Munitions. MSO is not appropriate for wastes in this category.

Large Cased Munitions. MSO is not appropriate for wastes in this category.

Table 7 summarizes the significant information for each of the destruction technologies reviewed.

TABLE 7. Summary of Destruction Technologies Reviewed.

Technology	Feed limitations	Wastestreams generated	Emissions	Status
Contained Detonation	Flexible, currently limited to < 100 lb of net explosive weight (waste plus donor) per event. Metal fragments cause additional deterioration of the chamber.	Bag house dust, pulverized contaminated pea gravel, casing residue.	Typical detonation emissions. Due to suppression of after-burning, products of incomplete combustion form (e.g., increased quantities of CO, CO_x, NO_x, volatile organic compounds (VOCs), SVOCs, and particulates).	Commercially available for up to 100 lb of RDX explosive equivalent per event. Emission treatment consists of bag house filtration down to 0.5 µm. Minimal handling of energetic wastes.
Contained Burn #1, Solid Rocket Motors	Rocket motors (propellants only).	Scrubber waste, bag house dust, casing.	Typical combustion emissions (CO_x, NO_x, VOCs, SVOCs, and particulates).	Developmental. Demonstrated on three types of rocket motors: 1. Large (17,450 lb) 2. Lead containing 3. Ammonium perchlorate containing May require redesign for different rocket motors. Minimal handling of energetic wastes.
Contained Burn #2, Confined Burn Facility	Bulk energetics, small cased munitions, energetic-contaminated wastes.	Burn residue, scrubber waste	Typical combustion emissions (CO_x, NO_x, VOCs, SVOCs, and particulates).	Early developmental. Completed testing with 10 lb of bulk energetics. Minimal handling of small ordnance.
Contained Burn #3, Energetic Contaminated Wastes	Energetic-contaminated wastes.	Burn residue.	Typical combustion emissions (CO_x, NO_x, VOCs, SVOCs, and particulates).	Commercially available.
Incineration, Rotary Kiln	Bulk energetics, small cased munitions (< 40 grams or < 20mm)	Ash, scrubber residues.	Typical combustion emissions (CO_x, NO_x, VOCs, SVOCs, and particulates).	Commercially available.
Incineration, Plasma Arc	Bulk energetics, small cased munitions, pyrotechnics	Ash, scrubber residues, slag.	Typical combustion emissions (CO_x, NO_x, VOCs, SVOCs, and particulates).	Developmental.
Incineration, Fluidized Bed	Energetic powders, liquids, slurries. Wastes with high ash content are undesirable.	Ash, scrubber residues.	Typical combustion emissions (CO_x, NO_x, VOCs, SVOCs, and particulates).	In use at Pine Bluff Arsenal. Treats up to 180 gal/hr.

TABLE 7. (Contd.)

Technology	Feed limitations	Wastestreams generated	Emissions	Status
Oxidation, Base Hydrolysis	Bulk energetics. The greater the surface area (smaller particle size) the more efficient the process.	Caustic/toxic aqueous wastestream, sludge.	Ammonia, NO, and N_2O.	BAE Systems, Royal Ordnance North America, Inc., Holston AAP has constructed and tested a 2,000-gallon hydrolysis reactor pilot plant.
Oxidation, Super Critical Water (Hydrothermal Oxidation)	Must be pumpable. Development is currently focused on treating wastes that were already pretreated by base hydrolysis.	Inorganic acids, salts, sludge.	No identified emissions.	Developmental. Looks promising but must address reliability problems before process becomes viable for implementation. Corrosion is a significant problem.
Oxidation, Molten Salt	Works best with liquids and slurries. Water, high ash content, and non-combustible solids are undesirable.	Salt, ash.	CO, NO_x, and typical combustion emissions.	Developmental. Rates as high as 5 pounds of energetics per hour have been demonstrated.

STEP 6. EVALUATION OF ALTERNATIVE TECHNOLOGIES

This section evaluates the destruction technologies described in Step 5 for more specific applicability to China Lake's energetic wastestreams, and compares them to OD. The goal of this section is to reduce the number of technologies to be considered so that a more detailed investigation of these technologies can be performed if needed. As stated in the objective, *an alternative will only be considered for implementation if it offers tangible advantages when compared with the current treatment method of OD.*

To reduce the complexity of the evaluation and comparison in this section to a reasonable level and still produce valuable information, one gross assumption is made to simplify the evaluation/comparison process.

Assumption

Each technology works as well as the developer(s)/vendor(s) claim. This assumption gives us an absolute "best case" for the alternative technologies. If the technologies do not compare favorably in this "best case" scenario, they do not warrant further consideration.

APPLICABILITY

Most of the reviewed treatment technologies only have the potential to treat specific categories of the China Lake wastestream (e.g., only bulk energetics, or bulk energetics and small cased munitions). Although it is theoretically possible to convert all of the cased munitions to bulk energetics using energetics removal technologies, the large variety of cased munitions and the unknown explosive hazards of the energetic materials in munitions that are experimental or have been damaged or altered make such conversion impractical because of either the complexity or the danger involved. Therefore, the applicability evaluation considers a technology a viable treatment method for a specific waste category only if an energetics removal technology is not required to convert the waste item to another bulk energetics waste category. Table 8 summarizes the applicability of each technology for the previously defined energetic waste categories.

Based on the information summarized in Table 8, six technologies are eliminated from further consideration; the reasons are listed in Table 9. Technologies remaining for consideration and comparison with OD are listed in Table 10.

TABLE 8. Applicability of Technologies to China Lake Wastestream.

Technology	Bulk energetics (28%)	Small cased (5%)	Medium cased (13%)	Large cased (54%)
Open Detonation	OK	OK	OK	OK
Contained Detonation	OK. Large blocks may have to be cut to appropriate size. Contaminated trash will require significant donor charge and special attention to arrangement of donor and waste to ensure a complete reaction.	OK. Fragments will significantly increase the maintenance and limit the life of the chamber.	Some OK. Total weight of energetic materials (donor plus waste) must be below chamber limit. Donor to waste ratio may be as high as 1:1. Fragments will significantly increase the maintenance and limit the life of the chamber. Heavy fragments may destroy the chamber.	NO. These items contain more energetic material than existing chambers can handle. In addition, fragments created by the detonation of munitions with heavy metal casings would destroy the chamber.
Contained Burn #1, Solid Rocket Motors	NO. Only applicable to solid rocket motors.	NO. Only applicable to solid rocket motors.	Only solid rocket motors. Additional development may be necessary for each size and type.	Only solid rocket motors. Additional development may be necessary for each size and type.
Contained Burn #2, Confined Burn Facility	OK	OK	NO. A detonation would be likely to occur.	NO. A detonation would be likely to occur.
Contained Burn #3, Energetic Contaminated Materials	Trash OK, bulk NO.	NO. Only for trash contaminated with energetics.	NO. Only for trash contaminated with energetics.	NO. Only for trash contaminated with energetics.

Should work for all items in this category with no pretreatment.

Requires minor pretreatment or will only work for some items in this category.

Will not work for items in this category. Items would require significant pretreatment to convert to bulk energetics category.

TABLE 8. (Contd.)

Technology	Bulk energetics (28%)	Small cased (5%)	Medium cased (13%)	Large cased (54%)
Incineration, Rotary Kiln	OK. Larger pieces may need size reduction.	OK	NO. Too large.	NO. Too large.
Incineration, Plasma Arc	OK. Larger pieces may need size reduction	OK	NO. Too large.	NO. Too large
Incinerator, Fluidized Bed	Powders, liquids, and slurries only. Size reduction required.	NO. Powders, liquids, and slurries only.	NO. Powders, liquids, and slurries only.	NO. Powders, liquids, and slurries only.
Oxidation, Base Hydrolysis	Size reduction, make into slurry. Does not work well on energetics prepared with hydroxyl terminated polybutadiene (HTPB) binder.	NO. Solutions or slurries only.	NO. Solutions or slurries only.	NO. Solutions or slurries only.
Oxidation, Super Critical Water	Solution or slurry only.	NO. Solutions or slurries only.	NO. Solutions or slurries only.	NO. Solutions or slurries only.
Oxidation, Molten Salt	Solution or slurry. Perhaps dry powders.	NO. Powders, liquids, and slurries only.	NO. Powders, liquids, and slurries only.	NO. Powders, liquids, and slurries only.

Should work for all items in this category with no pretreatment.

Requires minor pretreatment or will only work for some items in this category.

Will not work for items in this category. Items would require significant pretreatment to convert to bulk energetics category.

TABLE 9. Technologies Eliminated by the Specific Applicability Evaluation.

Technology	Reason for eliminating
Contained Burn #1, Solid Rocket Motors	This technology is only applicable to production demilitarization of inventory solid rocket motors. Static firing of China Lake's rocket motors from its RDT&E activities into the system would be potentially dangerous because they are experimental, damaged, or altered. Therefore, there is a high probability that a detonation would eventually occur. In addition, a system that accommodates a large variety of rocket motors has not been developed. The development of a flexible system would be an enormous effort and its usefulness would be unique to China Lake. In summary, while this technology is promising to demilitarization applications, its applicability to China Lake's wastestream is limited. Therefore, this technology is eliminated from further consideration.
Contained Burn #3, Energetic Contaminated Materials	This technology is only applicable to energetic contaminated waste (e.g., energetic-contaminated wipes and gloves), which is a small portion of the bulk energetics category (well less than the 28% of China Lake's wastestream average for the whole bulk energetics category). In many cases, the non-energetic component of the waste item is inseparable from the bulk energetics. Because of its limited applicability, and the small percentage and quantity of China Lake's energetic wastestream that this technology would treat, the value added by this technology is not considered significant. Therefore, this technology is eliminated from further consideration.
Incinerator, Fluidized Bed	This technology is only applicable to a portion of the bulk energetics category (less than the 28% of China Lake's wastestream average for the whole bulk energetics category). In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would eventually occur during this type of pretreatment. Therefore, this technology is eliminated from further consideration.

TABLE 9. (Contd.)

Technology	Reason for eliminating
Oxidation, Base Hydrolysis	This technology is only applicable to a portion of the bulk energetics category (less than the 28% of China Lake's wastestream average for the whole bulk energetics category). The applicability is further limited and complicated by its difficulty in treating energetics that are prepared with HTPB, a very common fuel/binder used for rocket propellants and explosives. In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would eventually occur during this type of pretreatment. Therefore, this technology is eliminated from further consideration.
Oxidation, Super Critical Water	This technology is only applicable to a portion of the bulk energetics category (less than the 28% of China Lake's wastestream average for the whole bulk energetics category). In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would eventually occur during this type of pretreatment. Therefore, this technology is eliminated from further consideration.
Oxidation, Molten Salt	This technology is only applicable to a portion of the bulk energetics category (less than the 28% of China Lake's wastestream average for the whole bulk energetics category). In addition, the pretreatment required to convert the wastes in the bulk energetics category to an appropriate feed slurry or powder is difficult and dangerous given the large variety and sometimes uncharacterized nature of the wastes. There is a high probability that a detonation would eventually occur during this type of pretreatment. Therefore, this technology is eliminated from further consideration.

TABLE 10. Technologies Remaining for Comparison With OD.

Technology	Bulk energetics (28%)	Small cased (5%)	Medium cased (13%)	Large cased (54%)
Open Detonation	OK	OK	OK	OK
Contained Detonation	OK. Large blocks may have to be cut to appropriate size. Contaminated trash will require significant donor charge and special attention to arrangement of donor and waste to ensure a complete reaction.	OK. Fragments will significantly increase the maintenance and limit the life of the chamber.	Some OK. Total weight of energetic materials (donor plus waste) must be below chamber limit. Donor to waste ratio may be as high as 1:1. Fragments will significantly increase the maintenance and limit the life of the chamber. Heavy fragments may destroy the chamber.	NO. These items contain more energetic material than existing chambers can handle. In addition, fragments created by the detonation of munitions with heavy metal casings would destroy the chamber.
Contained Burn #2, Confined Burn Facility	OK	OK	NO. A detonation would be likely to occur.	NO. A detonation would be likely to occur.
Incineration, Rotary Kiln	OK. Larger pieces may need size reduction.	OK	NO. Too large.	NO. Too large.
Incineration, Plasma Arc	OK. Larger pieces may need size reduction	OK	NO. Too large.	NO. Too large

Should work for all items in this category with no pretreatment.

Requires minor pretreatment or will only work for some items in this category.

Will not work for items in this category. Items would have to be converted to another category.

COMPARISON TO OD

There are many aspects of implementing and operating treatment technologies that must be considered when evaluating energetic waste treatment technologies for potential replacement of OD. Information summarizing some of the more critical criteria is listed in Table 11. A comprehensive list of questions that must be considered before making a final decision to implement an alternative to OD is given in the "Future Efforts" section at the end of this report.

A comparison of OD to the other treatment technologies for the major criteria listed in Table 11 is summarized below.

APPLICABILITY

OD is the only treatment method that will treat *all* of China Lake's wastestream. OD is also the only treatment method that can *safely* treat all of the waste items in the medium cased and large cased munitions categories. The other treatment methods evaluated in Table 11 treat the same fraction of China Lake's energetic wastestream (bulk, small cased, and some medium cased), which is typically less than half of China Lake's wastestream. If one or more of these methods were to be implemented, China Lake would still need to maintain its OD capability to treat more than 50% of its energetic wastestream (based on historical average).

IMPLEMENTATION

OD is the established method for treating energetic wastes at China Lake. Contained Detonation Chambers (100-pound capacity), Rotary Kiln Incinerators, and Plasma Arc Incinerators have all been constructed and demonstrated or used for full-scale or near full-scale throughput quantities. Design and construction would be relatively low risk, although some new design would be necessary to correct problems encountered by existing facilities and to optimize the system. The Confined Burn Facility has been demonstrated at a relatively low level of throughput (10-pound single event). Currently, efforts to scale up this technology to an 80 pounds per event demonstration are under way and scheduled for completion in December 2004. Design and construction of a full scale unit would follow the successful completion of the 80-pound demonstration. Design and construction of a Confined Burn Facility at China Lake prior to completion of the current development project would be very high risk. Therefore decisions concerning this technology should be deferred until that project is completed.

All alternative technologies, including those identified as commercially available, would require a significant amount of development and testing to optimize the system for treating China Lake's diverse wastestream and to ensure that it performs in compliance with current requirements.

TABLE 11. Information for Comparison of Technologies to OD.

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
APPLICABILITY					
Max. % of China Lake waste treatable	100%	54%	42%	42%	42%
Flexibility	Very flexible for all categories. The treatment limits in China Lake's permits vary, depending on the composition of items to be treated.	Flexible for bulk energetics, although size is a consideration. Flexible for small and medium munitions that can be detonated within unit quantity limits (largest unit constructed has design capacity of 100 lb of energetics (waste plus donor)). Fragment producing munitions are less desirable and will significantly increase maintenance requirements for or permanently damage the chamber.	Limited to energetics with a proven record of accomplishment for safe open burning. Items without a proven record for safe treatment will be required to undergo a burn study to determine safe quantities and configurations[a]. Generally, this system is applicable to waste that will burn, not detonate, with the exception of small contained munitions such as CADs, PADs, and small ignition devices that will not damage the blast hardened enclosure.	Current units are designed to accommodate some or all of the following: bulk energetics, small munitions, detonators, ignition cords, and wastes contaminated with energetic materials.	Flexibility is not determined. Development is focused on non-energetic wastes such as medical waste or contaminated blast media. Some development has been done toward treating small contained munitions such as CADs, PADs, pyrotechnics, colored smoke munitions, dyes, and range scrap.

[a] http://www.ih.navy.mil/cbf/objective.htm.

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
IMPLEMENTATION					
Maturity (level tested at)	Established method.	Advertised commercially available up to 100-lb net explosive weight. Demonstrated up to 45-lb bulk PETN.	Pilot scale. Demonstrated in 10-lb batches.	Operated at a commercial disposal facility and several Army facilities for treatment of bulk energetics and small cased munitions.	An MPTS has been fabricated and is being tested. So far the system has treated 2,000 lb of bullet tips (energetic range scrap) in 50 hr of initial testing.
Estimated capital cost to implement	$0	$3M for one 100-lb system.	$18.4M based on NSWC's estimate for implementation at their Indian Head facility.	$3M	$3-12M

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
IMPLEMENTATION (contd.)					
Public acceptance and permitting	The public has opposed OD at some other facilities, especially where urban encroachment of the facility has occurred. At China Lake urban encroachment is practically nonexistent. In addition, there is consistently positive public support of base operations.	At facilities where urban encroachment of the facility has occurred, the public has expressed a preference for contained detonation over OD. Currently, the primary advantage of the system over OD is that it reduces noise, overpressures from the detonation, and dust. The system also collects particulates down to 0.5 µm.	This is an emerging technology. The public response is unknown.	Historically, many special interest groups have been opposed to incineration, especially in California. However, there are at least four rotary kiln incinerators that are permitted to treat energetic wastes in the United States: 1. Lake City Army Ammunition Plant, Missouri 2. Iowa Army Ammunition Plant, Iowa 3. ICI Explosives Environmental, Joplin, Missouri 4. Tooele Army Depot, Utah	Plasma Arc Treatment systems have been permitted to operate in Alabama, and a commercial permit was secured to construct a system in San Diego, CA, for processing hospital waste (never implemented). The technology is classified by the State of California as an alternate treatment technology to incineration of medical waste and by the State of Washington for treating nuclear wastes (Hanford).

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
OPERATION					
Throughput	The China Lake facility can accommodate 15,000 lb of explosive weight per event (range limit for OD).	Advertised as 100 lb/event (waste plus donor). Multiple events can be done in a single day.	Still in development. Ultimate goal is 750 lb/hr.	Maximum of 200 lb/hr.	Still in development. Target is 500 lb/hr.
Significant process effluents	Typical detonation emissions and metal fragments. The major detonation emissions include CO_2, H_2O, and N_2.	Metal fragments, pulverized gravel, air pollution control unit residue, and typical burn/detonation emissions. The major burn/detonation emissions include CO, CO_2, H_2O, NO_x, and N_2.	Emissions from the burn that pass through the scrubbing system, burn residue, and residues from the scrubber, quench, rinse, and decontamination waters.	Residual solids and ash, bag house waste, recyclable metals. Scrubbing liquids can be dried, making the system a zero liquid discharge.	Glass slag byproduct, emissions from the pyrolysis that pass through the scrubbing system, scrubber residues, hydrogen, and carbon monoxide.
Components of full-scale system	Isolated detonation range	Pre-engineered metal building, detonation chamber, expansion tank, and air pollution control unit (particulates).	Burn chamber(s), ducts with quench water, surge tank, gas cleaning system, and control room.	Furnace with feed and discharge assemblies, air pollution control system, and control and gas monitoring system.	Waste feed assembly, process chamber with plasma torch, cooling system, gas scrubber, metal/glass collection/treatment system, control and operating system.

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
OPERATION (contd.)					
Reliability and maintainability	Very reliable with virtually no maintenance.	Smaller units have proven very reliable, especially when used with low fragmenting energetics. Larger unit (100-lb net explosive capacity) experienced leaking seals, weld failures, and a weak point at the mid-span of the chamber during testing. Design changes are under way.	To be determined. Still under development; reliability and maintainability unknown.	Reliable with reasonable maintenance.	Electrodes need to be replaced fairly frequently.
Resources (water and energy) and additional process materials required.	Donor and initiating explosives	Small amount of water for quenching and energy for operation of compressor/exhaust system. Donor and initiating explosives.	Energy to run fans and pump water for quench, neutralization, and scrubbing systems. Basic neutralizing solution, fuel, and water.	Fuel for primary and secondary combustion chambers (e.g., natural gas). Water and soda ash to quench and neutralize gases.	Electricity. Sodium bicarbonate or other neutralizing agent, anhydrous ammonia, water, argon, diesel fuel.

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
SAFETY					
Worker hazards associated with effluents	China Lake OD workers are approximately 1 mile from the detonation event, making hazards from effluents insignificant. Emissions are in compliance with all regulations, and the potential for public exposure is remote.	Because of the containment of the detonation, workers would typically be closer to the detonation site. The suppression of after-burning by the contained detonation process leads to a significant increase in carbon monoxide and unsaturated VOCs. Currently, the system only filters out particulates, so carbon monoxide and VOCs would still be emitted, creating a potential inhalation hazard for nearby workers.	Still too early in the development to be determined, but the robust scrubbing system planned for this technology would probably mitigate significant hazards associated with exhaust stack emissions.	Robust scrubbing systems for this technology typically mitigate significant hazards associated with exhaust stack emissions.	Not identified.

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
SAFETY (contd.)					
Worker hazards associated with process	Stacking the waste for OD is the most dangerous physical hazard of the operation. Because of the large throughput/event of this process, ODs are typically needed only once every month or two at China Lake, minimizing the amount of time personnel are exposed to the explosive hazards (average of a few hours a month for each worker).	Stacking the waste for detonation is the most hazardous aspect of the operation. If the waste must be reduced in size, the handling hazard would increase significantly. Because of the relatively small throughput, the amount of time personnel are exposed to the explosive hazards is significantly higher than with OD.	Loading the waste into the burn chamber would be the most dangerous physical hazard. The neutralizing solution and burn and scrubber residues present the greatest chemical hazards.	Automation, barricades, and extra thick kiln walls typically protect workers from explosion hazards during operation of the system. Handling the energetic wastes prior to incineration presents the most significant physical hazard, especially if larger bulk items have to be reduced in size. The neutralizing solution and incineration and scrubber residues present the greatest chemical hazards.	Not known.

TABLE 11. (Contd.)

Criteria	Technologies				
	Open detonation at China Lake	Contained detonation	Contained burn #2, confined burn facility	Incineration, rotary kiln	Incineration, plasma arc
HUMAN HEALTH AND THE ENVIRONMENT					
Does the system meet regulatory requirements with respect to process effluents released to the environment?	Data available indicate compliance due to the following features of the China Lake OD facility: 1. Minimal encroachment 2. Immense size of China Lake range 3. Surface water is 4 miles from the OD facility 4. No sensitive ecological receptors 5. Complex terrain 6. Long distance to human receptors.	Data available indicate compliance.	In development. System can be designed to accommodate different emission scrubbing systems.	With proper emission scrubbing, emissions are within limits established to protect human health and the environment.	Data available indicate compliance.

Regardless of whether an alternative technology is implemented, more than 50% of China Lake's wastestream would still have to be treated by OD. If an alternative were implemented, public acceptance and permitting issues for OD would have to be dealt with, in addition to any new issues resulting from the alternative.

OPERATION

Because of the simplicity and the ability to destroy relatively large volumes (15,000 pounds per event) of waste in a single event with minimal handling and manipulation, OD is by far the best process currently available.

SAFETY

Because of the simplicity of the process and the large throughput/event, OD is the safest of the technologies. The primary physical hazard when dealing with energetic wastes is bodily injury or death from spontaneous combustion or detonation of the waste items. The most effective way of mitigating this hazard is to minimize exposure to and manipulation of the energetic wastes. OD requires, by far, the least exposure to and the least handling of the energetic wastes. Under the current workload, China Lake's energetic wastes are typically treated by OD in a single event once each month. Each event takes about a half a day for setup time, and all personnel are at least 1 mile away during the detonation. All the other methods would require significantly longer direct exposure times to the energetic wastes because of the lower throughput and the complexity of the operation or equipment. In addition, alternative technologies typically require operational personnel to be relatively close to the treatment process, which may result in increased exposure to stack and fugitive emissions.

No additional chemical hazards exist with OD operations. All of the alternative processes require handling of filter or scrubber residues. The Confined Burn Facility, Rotary Kiln Incinerator, and Plasma Arc Incinerator processes also require the transportation of, handling of, and exposure to caustic chemicals for the scrubber system and other hazardous process materials.

HUMAN HEALTH AND THE ENVIRONMENT

While the efficiency of the OD process can be somewhat dictated by skilled stacking of the energetic wastes and donor and by choosing optimal weather conditions, OD emits a predetermined and unalterable quantity of effluents to the air, water, and land. A common thread among all the alternative technologies is that the final disposition of the process effluents to the air, water, and land can be, to some extent, controlled. However, this control at times results in a trade-off of one type of effluent (such as hazardous liquid waste) for another (fugitive air emissions), or one type of risk (potential detonation due to pretreatment operations) for another (potential health risk associated with fugitive emissions). All treatment methods for energetic wastes, OD and potential alternatives, require a dedicated piece of land with a surrounding safety zone.

China Lake is performing a Health Risk Assessment (HRA) of the treatment of its energetic wastes by OD operations. Before any alternatives are implemented, an HRA would also have to be completed for the chosen alternative(s).

CONCLUSION

None of the identified alternative technologies, either individually or collectively, will handle all of China Lake's energetic wastestream. For the portion of China Lake's wastestream that the identified alternatives will handle (bulk, small confined, and some of the medium confined), no single or multiple technologies stand out as a clear and attractive alternative to OD at China Lake. OD remains the safest, most flexible, and simplest method for treating China Lake's energetic hazardous wastestream.

FUTURE EFFORTS

Although this effort was unable to identify any clear and attractive alternatives to the OD of energetic wastes at China Lake, technology development is far from stagnant. The status of alternatives to OD should be reviewed periodically for applicability to China Lake's energetic wastestreams. It is recommended that a detailed review of China Lake's energetic wastes be made by an independent party, such as the Defense Ammunition Center, which specializes in implementing a wide variety of demilitarization technologies. In addition, technology developers should be made aware of the shortcomings of current technologies to safely and efficiently treat the wide variety of energetic waste generated in performing the RDT&E mission.

In preparing this report, it became obvious that a vast quantity of information must be obtained and considered before a decision is made to implement an alternative treatment method. A comprehensive list of questions that must ultimately be considered before making a final decision to implement an alternative to OD follows.

APPLICABILITY

1. What percentage of China Lake's energetic wastestream is treatable?

2. What are the feed requirements? How well is the entire process characterized with respect to the various feeds?

3. What pretreatments and post-treatments are required?

4. Is the system flexible? Can it accommodate changes in the wastestream?

IMPLEMENTATION

1. What is the process maturity? At what level has the technology been tested, and with what materials and in what configurations? Can the process be constructed with readily available equipment? Are there elements of the process and the integrated system that would be difficult to scale up?

2. What pretreatments and post-treatments are required? At what level have these technologies been tested, and with what materials and in what configurations? Can the processes be constructed with readily available equipment? Are there elements of the process and the integrated system that would be difficult to scale up?

3. What is the estimated capital cost to implement the technology?

4. What are the applicable Federal, state, and local requirements? Has the technology been demonstrated to meet or exceed these requirements?

5. What permits would be required? What data would be required in the permit application (e.g., emissions and public health risk assessment for cancer risk, and acute and chronic exposure risks)?

6. What is the likelihood of public acceptance?

7. What is the history of the technology with public acceptance, acquisition of permits, hazard assessments, nature of effluents, and known environmental concerns?

OPERATION

1. How effective is the process in treating the wastestream?

2. What are the process effluents (any gas, liquid, or solid produced by the system that can potentially be emitted, discharged, or released to the environment)? If applicable, how are they to be treated or disposed of?

3. What is the expected reliability and maintainability of the full scale system? What are the components of a complete system? How is the system integrated? What is the expected complexity of the full scale process?

4. How many operators and what skill levels are required?

5. What is the throughput?

6. What pretreatments and post-treatments are required? What physical or chemical hazards are associated with pre- and post-treatments?

7. What is the projected water demand?

8. What are the projected energy requirements?

9. What are the relevant Federal, state, and local requirements? What are the permitting and compliance reporting requirements?

10. What are the projected life-cycle costs? What are the projected operation and maintenance costs?

SAFETY

1. What are the process effluents (any gas, liquid, or solid produced by the system that can potentially be emitted, discharged, or released to the environment)? How well characterized are they?

2. What is the level of hazard or concern associated with potential and actual effluents to air?

3. What pretreatments and post-treatments are required? What hazards are associated with pre- and post-treatments? What are the effluents from pre- and post-treatments?

4. What process materials are used in the process? In what quantities are they used? How hazardous are they?

5. What are the physical hazards associated with normal operating conditions?

6. What personal protection equipment is required or recommended for workers? How well is worker protection achieved?

7. What are the potential incidents that could lead to worker exposure to chemical or physical hazards?

8. What are the potential incidents that could lead to public exposure to any hazardous material?

9. How hazardous are the materials being transported on-site?

10. How hazardous are the materials being transported off-site?

11. How many times are workers exposed to handling explosive hazardous waste during pretreatment, treatment, and post-treatment?

12. What is the time line associated with treatment? Will the explosive waste require further storage after pretreatment?

13. Can treatment be accomplished without adding additional hazards to personnel and property? If additional hazards will be present from processes, even if temporarily, will they inadvertently force emergency Level 1 responses?

14. Can the process be completely and safely stopped at any time in which a safety issue arises?

HUMAN HEALTH AND THE ENVIRONMENT

1. What are the process effluents (any gas, liquid, or solid produced by the system that can potentially be emitted, discharged, or released to the environment)? How well characterized are they?

2. What pretreatments and post-treatments are required? What are the process effluents? How well characterized are they?

3. What is the level of hazard or concern associated with potential and actual effluents to air?

4. What is the level of hazard or concern associated with potential and actual effluents to water?

5. What is the level of hazard or concern associated with potential and actual effluents to land?

6. What are the resource requirements (water, energy, and land-use)?

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ACRONYMS

ACWA	Assembled Chemical Weapons Assessment (Program)
AP	ammonium perchlorate
CAD	cartridge-actuated device
CO	carbon monoxide
CO_2	carbon dioxide
CS	o-chlorobenzylidine malononitrile
CWP	contaminated waste processor
DOD	Department of Defense
ECW	energetic contaminated waste
ft^3	cubic feet
HC	hexachloroethane
HE	high explosive
HEI-T	High Explosive Incendiary with Tracer
HMX	cyclotetramethylenetetranitramine
HRA	Health Risk Assessment
HTPB	hydroxyl terminated polybutadiene
L	liter
MAAP	Milan Army Ammunition Plant, Milan, Tennessee
MCBAT	Modified Contained Burn Assessment Test
MIDAS	Munitions Items Disposition Action System
MPTS	Mobile Plasma Treatment System
MSO	Molten Salt Oxidation
NAVAIR	Naval Air Systems Command
NAWS	Naval Air Weapons Station, China Lake, California
NC	nitrocellulose
NG	nitroglycerin
NQ	nitroguanidine
NSWC	Naval Surface Warfare Center, Indian Head, Maryland

OB	open burn
OD	open detonation
ORM	Operational Risk Management
PAD	propellant-actuated device
PBX	plastic-bonded explosive
PEAT	Plasma Energy Application Technology, Huntsville, Alabama
PETN	pentaerythrite tetranitrate
psig	pounds per square inch gauge
RAC	Risk Assessment Code
RDT&E	research, development, test, and evaluation
RDX	cyclotrimethylenetrinitramine
SCWO	super critical water oxidation
TNT	trinitrotoluene
TOC	total organic carbon
VOC	volatile organic compound`
WD	Weapons Division