ALTERNATIVE TECHNOLOGIES TO OPEN BURNING OF PROPELLANTS

1.0 INTRODUCTION

The Radford Army Ammunition Plant (RFAAP) has been formally involved in many research and development (R&D) initiatives to minimize and hopefully eliminate the open burning (OB) of propellants and other energetic material (EM). The R&D studies started in the 1980's when many of the OB/open detonation (OD) grounds were submitting their Part B Permit Applications. It should be noted that the RFAAP does not OD propellants. [1]

Two primary hazardous waste streams are generated at the RFAAP and treated onsite. One waste stream is clean, non-contaminated EM. This waste stream is generated from clean, off-specification propellant or residue or from cleaning processing equipment as one propellant formulation is switched to another propellant formulation for production. The second waste stream is EM contaminated with foreign object debris (FOD). This contaminated-EM is generated from propellant spilled on the production floors during equipment cleaning or small spills and propellant residue that has been washed into catch basins from the final cleaning step of the production floors. The contaminated-EM can contain floor sweepings of dirt, small paper items, metal, and/or gravel.

Since initiation of onsite waste treatment operations, a significant amount of propellant that was previously treated at the OB ground was reduced at the RFAAP by permitting an explosive waste incinerator (EWI) to treat the clean EM waste stream. The EWI is capable of grinding the non-contaminated EM, thermally destroying it, and treating the off-gases that are generated.

However, the contaminated-EM waste stream still goes to the OB ground for treatment, as the FOD cannot be safely processed through the incinerator's grinder system. The contaminated-EM waste stream has been significantly reduced over the years due to a downturn in production orders and an increase in waste minimization efforts. In the years prior to issuance of the initial RCRA permit for the burning ground, RFAAP treated, on average, approximately 62 tons per month at the OBG. [2] However, since permit inception, this number has steadily reduced. Over the last two years (2013-2014), an approximate 15 tons of contaminated-EM per month is treated at the burning ground. However, despite the greater than 75 percent reduction that has been achieved over the last 20 years, the OB ground treatment capability is still required at the RFAAP primarily due to the safety issues in preparing the contaminated-EM for incineration and the unique nature of some of the RFAAP's waste streams.

2.0 REVIEW PROCESS

In order to assess whether other treatment technologies are available that could replace or further reduce the need for open burning at the RFAAP, a literature review was conducted and potential alternatives for OB treatment were identified. The alternatives are shown separately in Table 1 listing the required criteria that need to be met. The alternative technologies that were fully developed were then evaluated in a Weighted Decision Matrix [3] to determine the best option against the status quo, OB treatment. The Decision Matrix Analysis, also known as Pugh Matrix Analysis, is a 6-sigma technique for making a decision that involves primary decision criterion against the available options (alternatives). The Decision Matrix is based on the American Society for Quality (ASQ) [4] multivoting approach to assist in defining a list of options narrowed to one choice based on consideration of the most important criteria. Defining the most important criteria were those identified in the literature review and input from RFAAP.

3.0 TECHNOLOGY ALTERNATIVES

Alternative technologies reviewed were those provided by the Virginia Department of Environmental Quality (VA DEQ), [1,5,6] those approved by the Department of Defense Explosives Safety Board (DDESB),[7, 8] and those currently at pilot-scale test status. [1, 8, 9, 10, 11]

3.1. VA DEQ Technologies Review

The VA DEQ provided information on the technologies from US Army Construction Engineering Research Laboratories (CERL): [1]

- Hydrothermal Oxidation (HTO)
- Supercritical Water Oxidation (SCWO) with pretreatment (as a modification to the HTO process)
- Wet Air Oxidation (WAO)
- Biodegradation and Composting
    - Aerobic degradation
    - Anaerobic degradation
    - Extremophilic microorganisms
    - Contaminated-soil composting
- Electrochemical Destruction (ED)

A detailed description of each of the technologies and the feasibility of their implementation at RFAAP is provided below. Further detail on the feasibility analysis is provided in the accompanying tables for each technology.

3.1.1. Hydrothermal Oxidation

The HTO treatment process utilized by CERL combined waste energetic material with an oxidant in water at pressures and temperatures above the critical point of water. In the referenced CERL study, pretreatment was performed on the waste using alkaline hydrolysis at a ratio of 1.2:1 wt./wt. sodium hydroxide to M31A1E1 propellant. It is not clear if the propellant was ground prior to alkaline hydrolysis. The pretreatment of M31A1E1 by alkaline hydrolysis was successful by breaking down the triple-base propellant into simple gases and soluble compounds.

Laboratory testing was also conducted on the pretreatment of M31A1E1 by supercritical carbon dioxide extraction. Milligram quantities of M31A1E1 were extracted, resulting in milliliter extractants containing parts-per-million (ppm) results. Only a fraction of the propellant ingredients were successfully extracted (22.5 %) in the process. This included the nitroglycerin (NG) base component, which resulted in safety concerns during testing. The other base components of nitroguanidine (NQ) and nitrocellulose (NC) could not be extracted. [1]

3.1.2. Supercritical Water Oxidation with Pretreatment

A modification of the HTO process that is currently being considered is the SCWO process with pretreatment. In this process, the initial waste stream is neutralized via a chemical reaction and the byproduct waste stream is treated via SCWO. The Army recently conducted a review of explosive neutralization followed by SCWO. [8] This process is not approved by the DDESB. In the Army's study, they cited that size reduction via grinding and alkaline hydrolysis of the granular propellant would be necessary for successful treatment. A description of the neutralization process followed by SCWO treatment is provided below.

Neutralization Process for SCWO

In 1998, Los Alamos National Laboratory neutralized high explosives by base hydrolysis. The explosives were reacted with concentrated base solutions of 1 to 8 M at elevated temperatures of 176 to 302 Fahrenheit (^{o} F). Since the temperatures were above the normal solution boiling points, the process was conducted in pressurized reactors. The bases were sodium hydroxide, potassium hydroxide, ammonium hydroxide, and sodium carbonate. Solvents were also used in the process depending on the type of explosive being tested for treatment. The primary solvent was water; other solvents tested were ethanol and dimethyl sulfoxide (DMSO) neat or in combination with water to minimize the mass transfer resistances to the reaction. During hydrolysis several reaction types can occur depending on the explosive being treated resulting in various oxidation/reduction and substitution/elimination reactions. The resultant product stream contains carboxylic acids, amines, sodium salts, ammonia, and gaseous nitrogen/nitrous oxide. [12]

Successful treatment conducting laboratory-scale hydrolysis occurred for nitramines and nitroaromatics resulting in water soluble, non-energetic products. Scale-up research occurred using 30 pounds of PBX 9404 (polymer-bonded explosive or plastic-bonded explosive); PBX 9404 is 94 % HMX (cyclotetramethylenetetranitramine), 3 % NC, 3 % chloroethylphosphate, and 0.1 % diphenylamine. It is in the form of a molding powder (up to 0.5-1 cm dia) or consolidated charges up to 35 pounds. The molding powder experiments were discontinued at 3 hours of treatment due to a slight exothermic reaction from the presence of NC. A consolidated charge was successfully held at optimum treatment conditions for 9 hours. After treatment, the reactor was cooled overnight and was then put on cycle for an additional 8.7 hours before undergoing one more cooling cycle. The total amount remaining of the PBX 9404 starting material was 6 %. [12]

Hydrolysis formation for SCWO testing was also conducted at RFAAP using a M28 surrogate propellant (prepared without the 2 % lead stearate for environmental reasons but containing approximately 60 % NC, 24 % NG, 10 % triacetin, 3 % dimethylphthalate, and 2 % 2-nitrodiphenylamine). The propellant was prepared in grains in the shape of right circular cylinders, 1/16-inch in diameter by 1/16-inch long. Several problems occurred with the large-scale treatment of the M28 surrogate. The most severe of these occurred on October 14, 2000, when the recirculation loop ruptured causing significant damage to the equipment. This included pump design considerations, recirculation intake location, screen mesh size for controlling migration of undersized energetics, and heat transfer inputs and outputs not integrated into a control system. Additional details of this incident can be found in the Phase II review of the National Academy of Sciences and Board on Army Science and Technology review committee evaluating alternative technologies for demilitarization. [13]

Based on the above discussion some of the propellants manufactured at the RFAAP would require solvent addition to swell the binders and allow access to the high explosives. Other propellants would require detailed calculations for each propellant type to control the hydrolysis process.

Today a batch prototype hydrolysis process is being developed for Cartridge Actuated Devices (CADs). [14] A CAD contains lead azide (40-50 %), hexanitrostilbene (25-35 %), potassium perchlorate (1-10 %), zirconium (5-15 %), fluoropolymer binder (1-10 %) and graphite (0.1-1 %). Less than 0.6 grams are in a hermetically sealed capsule of aluminum ranging from 0.5-inches in diameter by 2-inches long. A final performance verification test and a final technical systems audit is planned for this study but has not yet been performed.

Super Critical Water Oxidation

The hydrolysate from this neutralization process can then be treated by SCWO. Research on this process has continued since 1992. [15] The treatment technology uses the properties of water above its thermodynamic critical point (705 ^{o} F and 3,206 psi). Under these conditions the hydrolysate is completely oxidized, forming primarily carbon dioxide, water, salts, oxides of nitrogen, oxides of sulfur, and minimal particulates. Post-treatment is not required. It is not clear based on the literature citations if a SCWO unit is fully operational. Additionally, the DDESB has not approved this process. [16, 7]

The RFAAP was also involved in the testing of a bench-scale SCWO unit as part of the FY 2003 Congressional Interest Projects MANATEE (Managing Army Technologies for Environmental Enhancements) with CTC (Concurrent Technologies Corporation). [17, 18] Issues identified were process upsets causing corrosion of the reactor lining, precipitate of salts causing fouling and plugging, and slow reaction rates. The technology was not further pursued due to lack of test data for EM contaminated waste and the developmental nature of the SCWO technology.

3.1.3. Wet Air Oxidation

The WAO process uses elevated temperature in the presence of oxidizers to break down complex compounds to simpler compounds. Pretreatment in the CERL study was accomplished by alkaline hydrolysis. It is not clear if the propellant was ground prior to alkaline hydrolysis. The environment to conduct WAO processing is very corrosive and the best metal alloys have yet to be identified. The CERL testing was conducted on gram/liter mixtures. Waste products generated are residues of the propellant, high carbon oxygen demand (COD) and low biological oxygen demand (BOD) for further wastewater treatment. One of the oxidizers evaluated was ammonia nitrate, an ingredient is rocket propellants. Further research was recommended. No additional information on scale-up from laboratory to pilot-scale testing was identified for propellant treatment via WAO. [1]

3.1.4. Biodegradation and Composting

Trinitrotoluene (TNT) is the most studied EM for treatment by biodegradation because it can be degraded aerobically and anaerobically. Other energetics favor one method or the other. For example, RDX (cyclotrimethylenetrinitramine) and HMX are degraded under anaerobic conditions, and NG is biodegraded initially using an aerobic method followed by an additional aerobic and anaerobic degradation. Others such as NQ and NC either do not completely biodegrade or require alkaline hydrolysis pretreatment with additional microbial degradation that is not fully understood. Laboratory, pilot, and field composting studies were done on soils contaminated with trace amounts of explosives and/or propellants. Direct composting of the actual EM (explosive or propellant) did not occur. These studies took up to five months to complete the composting process. In the study, biodegradation of the propellants M31A1E1 and NOSIH-AA2 did not occur to any reasonable extent. Those studies that were successful consisted of degradation of the individual propellant chemicals separately and not those in the actual propellant samples in combination. Preparation of the EM by size reduction was identified as necessary to generate high area-to-mass ratios of the substrate for microorganisms to establish the desired biotransformation. Several other issues were also identified: toxicity, microorganism acclimation time, role of extremophilic microorganisms, and optimum EM composting conditions. [1]

In addition to the CERL study, the VA DEQ provided additional information on ARCTECH's Actodemil ® treatment and biodegradation technologies. [5, 6] Much like the CERL study, the bioremediation technologies only demonstrated promise for partial biodegradation of EM propellants; however, NG paste was successfully degraded with further treatment of the supernatant at the waste water treatment plant with is a biological treatment facility. [5] Additional discussion of this technology is presented in the section of technologies undergoing pilot-scale testing.

3.1.5. Electrochemical Destruction (ED)

EM compounds were evaluated for use as reactants in fuel cells to generate electricity. Only laboratory- scale experiments were performed on chemicals that are part of the EM propellant matrix. Some success occurred for reducing explosive materials such as TNT, NQ, and NG, but not for insoluble NC. The actual propellants of M31A1E1 and NOSIH-AA2 were not evaluated; however, the hydrolysates were evaluated. Only partial success on several chemical compounds in the hydrolysates occurred for electrochemical separation of the individual chemical ingredients. [1]

3.1.6. Assessment of VA DEQ Recommended Technologies

The primary requirement in each of the technologies recommended by VA DEQ for review is the preparation of the propellant waste. Preparation consists of size reduction of the propellant grain. The primary reason for size reduction is to break the case-hardened skin of the propellant grain to allow for a controlled treatment reaction of the specified treatment technology and to increase surface area for ease of treatment. Size reduction was not attempted on contaminated-EM. [1] As noted earlier by RFAAP and a quoted by CERL:

"The EM wastes may be contaminated with tramp metals, rocks, glass, wood, and other extraneous materials. Diminution, or size reduction, is an essential pretreatment step for all viable subsequent energetic waste treatment options. The smaller the size of the individual pieces of waste, the greater the treatability of the waste as well as the improved process control. However, conventional bladed grinding or shearing equipment cannot be used to effect diminution because of the unknown ingredients of these wastes. " [1 (p 28)]

Size reduction studies have been conducted on clean EM. In addition to traditional shreading, two promising technologies were hydromilling and liquid nitrogen treatment. Hydromilling with high pressure water produced a flow of water containing additional materials that then required treatment before final disposal. Liquid nitrogen was more promising since no additional waste stream was generated. Liquid nitrogen treatment used high pressure liquid nitrogen in a cryomill developed at the Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho, referred to as ZAWCAD (Zero Added Waste Cutting, Abrading and Drilling). The ZAWCAD performed cutting and abrading, without the introduction of a secondary waste stream of cutting media.

Safety hazards were identified for the hydromills that would prevent large-scale, frequent-use implementation. The ZAWCAD cryomill requires future research by adding solid carbon dioxide particles to the cutting jet, varying the feed rate, and expanding the array of propellant waste-types tested. [1]

3.2. DDESB-Approved Technologies Review

The DDESB has approved eight technologies for the treatment EM. Of the eight technologies two are for decontamination of "trace explosives-contaminated" material to a final "releasable to the public" condition. The six technologies approved for demilitarization applications include:

- Controlled Detonation or Donovan Chamber
- Deactivation Furnace (APE 1236)
- Static Detonation Chamber (SDC)
- Detonation of Ammunition in a Vacuum-Integrated Chamber (DAVINCH)
- Explosive Destruction System (EDS)
- Tactile Missile Demilitarization (TMD)

Of the six technologies approved, only one technology (APE 1236) was approved for treating bulk propellant. A detailed description of each of the technologies and the feasibility of their implementation at RFAAP is provided below. As with the VA DEQ recommended technologies, further detail on the feasibility analysis is provided in the accompanying tables for each technology.

3.2.1. Controlled Detonation Chamber (referred to as Donovan Chamber)

The Donovan Chamber is a blast chamber where munitions are packed in explosives and loaded into a large, double-walled steel chamber. Water-containing bags are also placed in the chamber for thermal control and steam generation. Blast energy is absorbed by pea gravel in the floor of the chamber. The explosive is detonated, which in turn breaks open the munition and detonates any energetics. There is an air pollution control unit that filters and treats the off-gases. The chambers are designed for the destruction of certain chemical munitions and can treat a maximum of 12 pounds of TNT equivalent, including the donor charge, at a time, resulting in a total of 19 pounds of single-base bulk propellant. A minimum of 20 minutes is required prior to reentry for placement of the next round. The chambers are intended for emergency use and not for routine use in a production environment. They are transportable in various sizes based on the type of munition to be treated. The chamber demonstrated the ability for destroying 105-millimeter (mm) high explosive (HE) munitions and is approved by the DDESB for use at Schofield Barracks, Hawaii, for certain chemical munitions. The Army reviewed the Donovan Chamber for the destruction of bulk propellants as currently designed and deemed it not to be suitable due to the variation of net explosive weights. [7, 8]

3.2.2. Deactivation Furnace (Ammunition Peculiar Equipment 1236 System)

The APE1236 deactivation furnace is a highly modified rotary kiln incinerator designed and developed specifically to thermally destroy conventional end-item munitions (complete rounds, projectiles, etc., in which propellant has been loaded and encased in the final production bullet). The Deactivation furnace includes the following major elements in order: rotary kiln, cyclone scrubber, afterburner, ceramic bag house, draft fan, and exhaust stack. The residence time of the furnace varies depending upon the rotational speed, length, and flight spacing in the furnace. For example, if the furnace rotational speed is set to one revolution per minute (rpm), it may take a feed item approximately 8 minutes to process through the kiln. To assure complete treatment of the feed item, the furnace is programmed based on the chemical analysis of the feed item, potential particulate matter, total chlorine content, semi-volatile metals, and low volatility metals. Per Army review, the residence time requirements would limit a feed rate for most bulk propellants to an average of 250 lbs./hour. This feed rate is for clean propellants and conventional end-item munitions and not for contaminated-EM waste. All feeds are manually fed. For example, the operator opens the scale door, puts in 10 bullets, closes door, and repeats every 15 seconds. Propellant is usually packaged in 1 to 2 pounds increments at a time in paper containers that have to be wetted to delay ignition to the middle of the kiln. The Deactivation Furnace is approved by the DDESB. [7, 8]

3.2.3. Static Detonation Chamber

The SDC is a hot detonation chamber designed by DYNASAFE. The SDC is designed for thermal decomposition and controlled deflagration and burning of high explosives and propellants. The chamber has been demonstrated capable of destroying the widest assortment of ammunition, such as fuzes, small arms, cartridge ammunition, mortars, large projectiles, small amounts of bulk explosives and propellants, and Chemical Warfare Agents (CWA), including those containing projectiles. The chamber is approved by the DDESB. The treatment capability of the chamber is routinely 5.29 pounds of TNT-equivalent (equivalent to approximately 11 pounds of single-base propellant) per cycle. The detonation chamber can operate in pyrolytic or oxidizing environments. The munitions are heated to 752 to 1112 ^{o} F resulting in deflagration, detonation or burning of the munition explosive fill. The shock wave from detonation can be as high as 9.87 atmospheres. The throughput is limited for bulk propellant since the chamber is operated in a continuous, semi-batch mode and varies greatly with munition; for example, an 8-inch projectile has a throughput rate of 20/day whereas a 155-mm projectile has a throughput rate of 40/cycle, and 105-mm projectiles or 4.2-inch mortar rounds has a throughput of 120/day. Using the maximum throughput rate for the 4.2-mortar round having a potential maximum amount of TNT equivalent of 6.6 pounds (depends if the mortar is an M1, M2, M3, or M4), only 1268 pounds of single-base could be processed per day. To date only 36 pounds of bulk propellant have been tested in a given load cycle. [7, 8, 20]

3.2.4. Detonation of Ammunition in a Vacuum-Integrated Chamber

The DAVINCH is similar to the DONOVAN chamber in that the system consists of a detonation chamber where energetic material are placed in the chamber and are surrounded by donor explosives. The donor explosives are detonated to shatter the munitions; the shock and heat of the explosion destroys the chemical agent and energetics. To date, this process has been limited to chemical warfare agents. Off-gases from the DAVINCH are converted to oxides of carbon via treatment with a cold plasma oxidizer; a minimal liquid residue condensate stream is generated. A rinsate is used for clean-up of the chamber and treated for proper disposal. The scrap metal is then recycled.

The DAVINCH was designed for fragmenting munitions and solid rocket motors. The system has a total capacity of approximately 68 pounds of TNT equivalent. The system is designed as a detonation chamber, in which 60 % of the total TNT equivalent is used for detonation, thereby, only 44 pounds of single-base propellant could be treated at a time. Testing has been completed on HD projectiles (mustard agent) with a throughput of 9 projectiles/10 hour day; if 60 % of the total TNT equivalent is used for detonation, then this results in treating 396 lbs. of single-base propellants/ 10 hour day.

The DAVINCH is approved by the DDESB; however, the Army documented that the DAVINCH is not intended for the treatment of bulk propellants and also does not provide significant throughput capacity of bulk propellants. [7, 8]

3.2.5. Explosive Destruction System (EDS)

The EDS uses cutting charges to destroy chemical munitions by external (implosion) detonation. The system is primarily a sealed, stainless steel containment vessel that contains the blast, vapor and munition fragments. The EDS is designed for mortars, shells, projectiles and bomblets. [21]

The treatment capacity of the EDS is between 1.5 and 9 pounds TNT equivalent (e.g., three, 4.2-inch mortars up to six, 4.2-inch mortars, or 2.4 to 14.4 pounds of single-base propellant) pending on the design and retrofit and mortar-type which determines the TNT fill amount. This technology is limited in terms of the size of munition they can handle and their processing rate. The individual units can only deal with relatively small munitions at a slow rate due to the generation of a liquid waste stream that requires disposal from a time-consuming neutralization step. Only one detonation can occur every other day per EDS.

There are only five transportable EDS units available through the Army used for emergency situations. The EDS is approved by the DDESB; however, it is neither designed for nor suitable for the destruction of bulk propellants. [7, 8]

3.2.6. Tactical Missile Demilitarization

The TMD unit is located at Letterkenny Army Depot, Chambersburg, Pennsylvania. The TMD is designed to destroy large tactical missiles by sectioning the missiles and removing the EM for partial recycle or open burning and hardware decontamination.

Specifically, the TMD is a fully integrated operation consisting of modules. Low and high value energetics are brought into the Horizontal Disassembly module where missile and motors are disassembled, propellants are removed or milled, and warheads are removed and milled. The low value energetics are further processed in the Slurry Explosive module into commercial blasting explosives. The high value energetics are further processed in the Energetics Processing module where the recovery of propellant and warhead feed stocks occur. Any metal parts such as missile components for reuse are decontaminated in the Hardware Decontamination module. Non-value products are destroyed in a Destruction module via a blast chamber or a contained burn (OB/OD). Waste from all modules are properly disposed. The TMD is approved by the DDESB; however, it is not approved for the destruction of bulk propellants. [7, 8, 22]

3.3. Technologies Undergoing Pilot-Scale Testing

In addition to those technologies currently approved by the DDESB, there are several technologies currently undergoing pilot-scale testing that could eventually be approved and considered for replacement of the OB ground. These include:

- Plasma Arc Pyrolysis
- Molten-Salt Oxidation (MSO) Pyrolysis
- ARCTECH's Actodemil ® Treatment Technology
- Decineration™ Rotary Furnace System

3.3.1. Plasma Arc Pyrolysis

A plasma arc operates similar to an arc-welding machine. A high energy ionized gaseous arc is generated between two electrodes creating high temperatures from 5,432 to 12,632°F. Waste material is broken down into its elemental atoms and then recombined into harmless gases and oxidized to carbon dioxide and water in ceramic bed oxidizers. Some of the patent information recommends particles are not greater than about 5/8-inch nominal diameter to minimize slag formation. [23] Currently the technology is effective for the treatment of liquids and has had some application to end-product munitions. [24] The last detailed research report for treatment of liquids is in 2002. [25] The Naval Surface Warfare Center, Carderock Division (NSWCCD) with PyroGenesis, Incorporated, in Montreal, Canada, worked on a pilot-scale treatment system. Propellants were not directly tested in this system; only items that may or may not be contaminated with chemical warfare agents and other hazardous substances such as dunnage wood, contaminated soils, etc. This system required the solids to be pulverized into fine fibers of approximately 15 microns in diameter and not exceeding 4 % moisture content prior to treatment. Testing of full-up ammunition has also occurred for metals recovery in other pilot units. The slag generated from these tests continued to feed the arc, however, fouling of the system kept occurring. The end-product munitions studies have been currently put on hold by the US Army due to extensive project and design delays and funding concerns.

3.3.2. Molten-Salt Oxidation (MSO) Pyrolysis

Another form of pyrolysis, MSO, is a thermal, non-flame process capable of oxidizing organic compounds in a salt, primarily molten carbonate. MSO operates at 1,022°F and produces a clean off-gas. Independent research was conducted at Lawrence Livermore National Laboratory (LLNL), Livermore, California, and the Naval Surface Warfare Center, Indian Head Division in Indian Head, Maryland. The LLNL developed an integrated pilot-scale MSO treatment system.[26] The explosives tested in LLNL pilot-scale unit were RDX, HMX, TNT, PBX 9404, and some of the LX series, like LX-10, a high energy density solid explosive consisting of 94.5% octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) and 5.5% Viton A Binder. Their main concern was keeping the molten salt dry by minimizing water condensation. The testing at Naval Surface Warfare Center was conducted in bench-scale units where most of the work was on individual components of solid fuels and inert waste material of composite and double-base propellants. There was incomplete and slow oxidation of paper, cotton and plastics. The 1995 research papers described a need to increase oxidizing potential by adding additional nitrates to the carbonate and ensure that a ternary eutectic melt occurs. [24, 27]

In 2011, a review of MSO was conducted by Yao, et al. In these studies, part of the problem documented with MSO was attaining the desired destruction and removal efficiencies for particular compounds. MSO for the treatment of propellants was largely abandoned when funding was withdrawn because it was slow and did not oxidize all components completely. [28] In the study documentation, the principal investigator, Yao, commented:

> *"Although many experiments using the MSO process have been conducted, some issues remain unresolved. Further studies are needed in the following areas: (1) Significant research is needed to verify the destruction efficiency for a variety of wastes, identify the most suitable waste stream or waste types for the MSO process, refine the spent salt handling and reprocessing technology, and resolving engineering issues associated with materials and scaling up to a pilot project at the commercial level. (2) The effects of factors such as temperatures, gas hold-up, and the oxidizing air feed rate on DREs [destruction removal efficiency] need to be investigated on a larger scale, to provide more fundamental data for system design. Moreover, detailed economic information for a demonstration-sized system is not currently available for many wastes. (3) The spent salt from the MSO system will require further separations or other processing to prepare them for final disposal. The purity and recycling cost of the mixture need to be investigated. For mixed wastes, the best result currently possible is a minimum usable volume, and the acceptable final solid forms are likely to incorporate the residues into cements, glass, ceramics, or sulfur polymer materials. The viability of processing residues into such solid forms remains to be demonstrated. And (4) various auxiliary fuels, such as propane, need to be tested, for controlling and maintaining the desired temperatures and thus minimizing the operating costs."* [28]

3.3.3. ARCTECH's Actodemil ® Treatment Technology

ARCTECH's Actodemil® technology is chemical hydrolysis process that converts explosive or energetic chemicals into a harmless product by eliminating the explosives properties of the propellant and recycling them into fertilizer. [29]

The Actodemil® process is actually a two-step process. The first step is hydrolysis of the propellant with highly alkalized organic water soluble humic/fulvic humate salt made to 6 N potassium hydroxide (used for land application) or sodium hydroxide (used if disposed) and proprietary additives. The alkaline mixture is preheated to 176°F. Propellants are then slowly added to the preheated mixture without grinding and size reduction and are gently mixed. Digestion of the propellant is considered complete based on the pH and alkalinity measurement of the resultant liquid. In a number of runs of 2,000-pound batches of single-base propellant, a minimum of 6 hours was required to eliminate the explosive properties of the propellant. The process is inherently safe as the explosives are being reacted under a water-based reagent.

The second step of the process is neutralization/oxidation. After the explosive properties of the material are eliminated, the pH is adjusted with phosphoric acid to near neutral pending on the end use of the product. Nitrogen oxide gas is generated and treated with a wet scrubber to capture the off-gas. The spent scrubber reagent also becomes part of the fertilizer product.

While promising on the surface, concerns were expressed with other propellant ingredients that made their way from the initial EM to the end-product fertilizer. For example, toxicity characteristic leaching procedure (TCLP) data for fertilizer made from a single-base propellant showed the detection of barium, chromium, and lead above the reporting limits. This is especially of concern when the ultimate final goal of the product is to spread it on fields that will produce crops and animal products for human consumption.

ARCTECH's technology has recently been reviewed by the DDESB, but is not approved. [8]

3.3.4. Decineration™ Rotary Furnace System

This process involves reduction of energetic materials in a pyrolytic environment within a rotary furnace similar to that used with the APE1236 system. The furnace is then equipped with air pollution control equipment to treat the off-gases that are generated. It was developed for conventional end-item munitions under Research, Development, and Demonstration (RD&D) permit, per R315-6.5. [30] The furnace can treat certain propellants, explosives, and pyrotechnics. The system was specifically designed for low temperature thermal demilitarization of ammunition ranging from small arms through 20 mm and is intended as an alternative to the APE1236 system. As with the APE1236 system, ammunition larger than 20 mm must be disassembled prior to feeding into the furnace. Bulk propellants were not tested in the RD&R unit. This system is not approved by the DDESB.

4.0 ASSESSMENT OF IDENTIFIED ALTERNATIVES

All of the fifteen technologies researched are identified in Table 1 with HTO and SCWO with pretreatment combined. Table 1 is highlighted by the three groupings of technologies reviewed. For example, the five technologies VA DEQ suggested for review is one color, the six technologies approved by the DDESB is in another color, and the four technologies undergoing pilot-scale testing is in another color. Of those technologies identified above, only those that were available as a pilot or production scale operations were assessed in the technology review. This included eight different technologies as highlighted in green at the bottom of Table 1:

- HTO/SCWO
- Donovan Chamber
- APE1236 Deactivation Furnace
- SDC
- DAVINCH
- EDS
- Actodemil®
- Deincineration™

In reviewing the viable alternatives, the assessment considered six key criteria that would affect the feasibility of implementation at RFAAP as either as a replacement to open burning. These criteria included:

- Safety hazards
- Waste stream variability
- Environmental releases
- Engineering controls
- Layout possibilities
- Support.

The definitions and the specifics of these criteria to the technology are defined in Table 1.

For each technology, an individual decision matrix was developed to assess the viability of the technology against the six criteria identified above. (Reference Tables 2 through 9) The Weighted Decision Matrix was designed as a table with the rows containing the options and the column containing the criteria. Each criterion was then weighted based on importance to the RFAAP. The weights are a “1”, “2” or a “3”, where the “3” is more important than a “2” and a “1”, and the “3” and “2” are more important than a “1”. The relative weights for each option criterion is on a scale of “-3” to “+3”, with “0” being no change from the status quo, minuses are worse than the status quo, and pluses are better than the status quo. The arrays of the weights and criterions are multiplied together then summed up to provide a result. Positive results are better than the status quo and negative results are worse than the status quo.

The results from each of the individual technology assessments were then summarized in the Weighted Decision Matrix (Table 10) to provide a final assessment of each technology versus the status quo.

5.0 SUMMARY OF FINDINGS

The results of the assessment, which are summarized in Table 10, show that the status quo should be maintained as the current technology at RFAAP for the following reasons:

- The safety hazards, which were identified as the most important criteria to RFAAP, are well understood with the current technology and the lack of understanding for alternative technologies creates unacceptable levels of risk and liability.
- Waste stream variability at the RFAAP would require implementation of some sort of pre-treatment step, FOD removal, or a TNT equivalent restriction that the current technology

does not require. Each of these bring with them inherent safety hazards and engineering difficulties.

- Engineering controls are simple and maintenance and monitoring are well defined for the current technology. There are no high pressure, temperature control issues or corrosive environments.
- Layout of the site already exists and is well understood. The DOT and MIL-STD 286 required arcs have to be considered and varies for each type of operation. For example, during testing of SCWO with pretreatment, RFAAP manufactured the M28 hydrolysate in a tank in one of the inactive NC production lines and then tested the hydrolysate in an inactive water dry building.
- Support of set-up instructions for new propellants can be obtained from the Army and hazardous analysis testing, whereas support for untested materials in the alternative technologies involves a much more complex approval matrix, if one is available at all.

The one criterion of environmental releases for the status quo is the limiting factor that will become better understood when the planned air quality sampling of an open burn of Mark 90 rocket motors is conducted by the EPA. Current emission estimates for the OB ground are based on limited testing at other facilities in contained chambers. The sampling offered by EPA will provide direct assessment of unit emissions and provide a real basis on which a comparison can be made to the alternatives.

6.0 RECOMMENDATIONS

The RFAAP is the only NC-based propellant manufacturing plant in the United States. It is a flexible plant using a very simplistic infrastructure designed to produce over 40 different types of propellants. This simplicity can result in propellant waste generation containing FOD during transitioning from one product to another on the same production line. The Waste Minimization Plan, Attachment III.B of the permit application, summarizes the waste minimization goals for the plant. Included in these goals is a continued effort to target redirection of waste materials from the OB ground either back into the process or to other treatment solutions that provide control of air pollutant emissions, reduce the amounts of energetic waste containing lead generated on the facility and in turn reduce the amount of energetic waste going to the OB ground, and continue to evaluate methods to modernize operations and waste treatment technologies in tracking the development of alternative technologies to supplement or eliminate the use of the OB ground. Each of these goals is implemented on a program, production, and individual operation basis through a variety of methods.

Until a mature technology that can manage FOD-containing, NC-based propellant waste is developed to reliably supplement or eliminate the use of the OB ground, it is recommended the OB ground continue to operate.

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Table 1-Technology vs. Criteria

		VA DEQ TECHNOLOGIES REVIEWED				DDESB-APPROVED TECHNOLIGIES REVIEW						TECHNOLOGIES UNDERGOING PILOT-SCALE TESTING			
		HTO/SCWO	WAO	Biodegradation and Composting	ED	Donovan Chamber	APE 1236	SDC	DAVINCH	EDS	TMD	Plasma Arc Pyrolysis	MSO	Actodemil ®	Decineration™ Rotary Furnace System
Criteria	**Definition**	**Criterion Specifics to Technology**													
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Cannot treat propellants directly and hydrolysate generation requires strict parameter control	Corrosive environment and potential use of ammonia nitrate	Total biodegradation did not occur in 5 months and toxicity issues occurred	Total reduction of insoluble NC did not occur	Not recommended for bulk propellants per Feb 2015 Army review due to 12 lbs. of TNT equivalent (19 lbs. single-base) can only be treated and a minimum of 20-minutes wait time is required before next treatment cycle can be prepped	Propellant feed control needed. All feeds are manually fed where the operator opens the scale door, puts in 10 bullets, closes door, and repeats every 15 seconds. Propellant is usually packaged in 1 to 2 lbs. increments at a time in paper containers that have to be wetted to delay ignition to the middle of the kiln.	Demonstrated for treatment of bulk propellant	Not recommended for bulk propellants per Feb 2015 Army review due to same reasoning for the similar Donovan Chamber	Not recommended for bulk propellants per Feb 2015 Army review since only one detonation can occur every other day per EDS.	Not recommended for bulk propellants per Feb 2015 Army review. Technology is for large tactical missiles demil by sectioning the missiles and removing the EM for partial recycle or open burning and hardware decontamination.	Not for use with bulk propellants; bulk propellant would have to be liquefied into small particles	Incomplete oxidation of propellants	Propellant digestion requires strict parameter control	No testing of bulk propellants occurred
Waste stream variability	How much flexibility and support is provided by each technology	Size reduction required	Size reduction required	Size reduction and NC alkaline hydrolysis is required	Only for propellant ingredients, not complete propellant formulations	Intended for certain chemical munitions and not bulk propellant	Development for conventional end-item munitions in a semi-batch processing mode	Can only treat 5.29 lbs. TNT equivalent or 11 lbs. of single-base propellant (significantly undersized for RFAAP demand)	Treatment is destruction via detonation	Treatment is destruction by external detonation	Not flexible for bulk propellants	Demonstrated inflexibility in previous estimates and unfunded by JMC due to inflexibility	Cannot treat paper, cotton or plastics	Not demonstrated for variable propellant waste streams	Low temperature restricts treatment options
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	No unusual post-treatment requirements	Laboratory-scale testing only	Various compost residues requiring permitting	Technology not well developed to identify potential releases	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and treatment residues	Off-gases and TCLP metals in the fertilizer from metal-containing propellants	Off-gases and treatment residues
Engineering controls	Ease of managing treatment technology and maintaining equipment	Maintenance issues with high pressure and temperature controls	Maintenance issues with corrosive environment	Microorganism acclimation time	Technology not well developed to identify engineering controls	Minimal issues if treat the chemical munitions per unit design	Minimal issues if treat the chemical munitions per unit design	Minimal issues if treat the chemical munitions per unit design	Minimal issues if treat the chemical munitions per unit design	Minimal issues if treat the chemical munitions per unit design	Significant variability in the demil portion of the process	Technology is not well developed for bulk propellants	Technology is not well developed	Primary equipment is off-shelf items-mixers, pH control, propellant feed control, etc.	Technology in the RD&D phase.
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	When RFAAP processed hydrolysate in a large production tank and conducted bench-scale testing in SCWO unit, inactive buildings were used to met arc requirements	Scale-up from laboratory to pilot-scale testing does not exist	Minimum of 25 acres	Scale-up from laboratory to pilot-scale testing does not exist	Technology is a mobile system	Incineration-type technology requiring several acres that can meet the arc requirements	Incineration-type technology requiring several acres that can meet the arc requirements	Incineration-type technology requiring several acres that can meet the arc requirements	Incineration-type technology requiring several acres that can meet the arc requirements	Primary treatment of demilled material is open burning	Pilot-scale testing does not exist	Pilot-scale testing has been discontinued	3 acres per processing line (pounds of propellant treated per line depends on propellant type)	Incineration-type technology requiring several acres that can meet the arc requirements
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Poor to Fair	Poor	Fair to Good	Poor to Fair	Good	Good	Good	Good	Good	Fair to Good	Poor	Poor to Fair	Fair to Good	Fair to Good
	Pilot or Production Units Available	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes

Key:

HTO/SCWO-Hydrothermal Oxidation (HTO) or Supercritical Water Oxidation (SCWO) with Pretreatment
WAO-Wet Air Oxidation
Biodegradation and Composting-composting is a subset of bioremediation
ED-Electrochemical Destruction
Donovan Chamber-Controlled Detonation Chamber (referred to as Donovan Chamber)
APE 1236-Deactivation Furnace APE (Ammunition Peculiar Equipment) 1236 System
SDC-Static Detonation Chamber
DAVINCH-Detonation of Ammunition in a Vacuum-Integrated Chamber
EDS-Explosive Destruction System
TMD-Tactical Missile Demilitarization
Plasma Arc Pyrolysis
MSO-Molten-Salt Oxidation Pyrolysis
Actodemil ®-ARCTECH's Actodemil ® Treatment Technology
Decineration™ Rotary Furnace System

Table 2. VA DEQ TECHNOLOGIES REVIEWED-HTO/SCWO-Hydrothermal Oxidation (HTO) or Supercritical Water Oxidation (SCWO) with Pretreatment

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Cannot treat propellants directly and hydrolysate generation requires strict parameter control	Requires segregation of propellants	Requires additional chemicals	Requires high pressure equipment	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Size reduction required	Requires size reduction for pretreatment	Can process multi- and single-base propellants, if propellant is clean and segregated	Various solvents are required to prepare the hydrolysates	N/A	Can prepare hydrolysate for individual propellant ingredients	Can manage variable hydrolysates	Works best on Cartridge Actuated Devices hydrosulfates
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	No unusual post-treatment requirements	N/A	N/A	N/A	N/A	Standard permitting of post-treatment units	Off-gases from making hydrolysate can be treated	Post-treatment of hydrolysate residues can feed standard waste water treatment plants
Engineering controls	Ease of managing treatment technology and maintaining equipment	Maintenance issues with high pressure and temperature controls	Testing at RFAAP required daily non-routine maintenance to keep equipment operational	SCWO units are operated intermediately and require a back-up unit for daily operation	High level of expertise and training were required for the Blue Grass Chemical Agent Destruction Pilot Plant project	N/A	N/A	N/A	N/A
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	When RFAAP processed hydrolysate in a large production tank and conducted bench-scale testing in SCWO unit, inactive buildings were used to met arc requirements	Requires reactivation of a standby-by areas	N/A	N/A	N/A	N/A	Requires 25 acres	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Poor to Fair	N/A	Army has units that are not routinely operated. Only one primary contractor exists on the SCWO designs for propellant hydrolysate.	The Blue Grass Chemical Agent Destruction Pilot Plant project is behind schedule	N/A	N/A	N/A	N/A

Table 3. DDESB-APPROVED TECHNOLIGIES REVIEWD-Controlled Detonation Chamber (referred to as Donovan Chamber)

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Not recommended for bulk propellants per Feb 2015 Army review due to 12 lbs. of TNT equivalent (19 lbs. single-base) can only be treated and a minimum of 20-minutes wait time is required before next treatment cycle can be prepped	Requires additional explosives to treat propellants	Requires water bags for thermal control and steam generation	Requires high pressure equipment (blast chamber)	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Intended for certain chemical munitions and not bulk propellant	Cannot process combinations of multi- and single-base propellants	Not designed for bulk propellants	Designed to treat specific HE munitions	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and treatment residues	N/A	N/A	N/A	N/A	Standard permitting of post-treatment units	Off-gases can be treated	Post-treatment of blast residues (liquid and ash) can be managed
Engineering controls	Ease of managing treatment technology and maintaining equipment	Minimal issues if treat the chemical munitions per unit design	N/A	N/A	N/A	N/A	Technology is well understood by the Army	Off-gases can be treated	Minimal engineering controls for operations
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	Technology is a mobile system	May require reactivation of a standby-by area	N/A	N/A	N/A	Technology is a mobile system intended for emergency use	N/A	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Good	N/A	N/A	N/A	Well understood by the Army using batch treatment method like status quo only in smaller quantities at a time	N/A	N/A	N/A

Table 4. DDESB-APPROVED TECHNOLIGIES REVIEWD-APE 1236-Deactivation Furnace

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Propellant feed control needed. All feeds are manually fed where the operator opens the scale door, puts in 10 bullets, closes door, and repeats every 15 seconds. Propellant is usually packaged in 1 to 2 lbs. increments at a time in paper containers that have to be wetted to delay ignition to the middle of the kiln.	Feed system is a batch process where 1 to2 lb. of propellant is wetted then hand-fed into the kiln	Propellant handling issues	Requires personnel direct exposure	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Development for conventional end-item munitions in a semi-batch processing mode	Propellant matrix needs to be consistent for the operational recipe	Not designed for bulk propellants	Developed for conventional end-item munitions	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and treatment residues	N/A	N/A	N/A	N/A	Standard permitting of post-treatment units	Off-gases can be treated	Post-treatment of residues can be managed
Engineering controls	Ease of managing treatment technology and maintaining equipment	Minimal issues if treat the chemical munitions per unit design	N/A	N/A	Control system and recipe make-up needs to be upgraded	N/A	Technology is well understood by the Army	Off-gases can be treated	Incineration-type engineering controls for operations
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	Incineration-type technology requiring several acres that can meet the arc requirements	Site plan may be an issue with arc requirements	N/A	N/A	N/A	N/A	May require reactivation of a standby-by area	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Good	N/A	N/A	N/A	N/A	N/A	Well understood by the Army using a semi-batch processing mode	N/A

Table 5. DDESB-APPROVED TECHNOLIGIES REVIEWD-SDC-Static Detonation Chamber

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Demonstrated for treatment of bulk propellant	A batch process treating 5.29 lbs. TNT equivalent (~11 lbs. of single-base propellant) at a time resulting in high personnel exposure	Chamber can treat the widest assortment of munitions but limited for bulk propellants	Requires continuous personnel exposure for making small batches	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Can only treat 5.29 lbs. TNT equivalent or 11 lbs. of single-base propellant (significantly undersized for RFAAP demand)	Only 36 pounds of bulk propellant have been tested	Not designed for bulk propellants	Developed for treating small assortment of munitions	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and treatment residues	N/A	N/A	N/A	N/A	Standard permitting of post-treatment units	Off-gases are cleaned by separate Dynasafe Off-Gas Treatment (OGT) systems	Post-treatment of residues can be managed
Engineering controls	Ease of managing treatment technology and maintaining equipment	Minimal issues if treat the chemical munitions per unit design	N/A	N/A	N/A	N/A	Technology is well understood by the Army	System may be mobile, semi-mobile or stationary as well as containerized	First "turn-key" contract for the installation and required infrastructure for a SDC 1200C (SDC) was finalized Dec 23, 2014. Commissioning will be in 2016.
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	Incineration-type technology requiring several acres that can meet the arc requirements	Site plan may be an issue with arc requirements	N/A	N/A	N/A	N/A	May require reactivation of a standby-by area	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Good	N/A	N/A	N/A	N/A	N/A	Well understood by the Army using an automated semi-batch processing mode	N/A

Table 6. DDESB-APPROVED TECHNOLIGIES REVIEWD-DAVINCH (Detonation of Ammunition in a Vacuum-Integrated Chamber)

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Not recommended for bulk propellants per Feb 2015 Army review due to same reasoning for the similar Donovan Chamber	A batch process treating ~68 lbs. TNT equivalent (~141 lbs. of single-base propellant) at a time resulting in high personnel exposure	Chamber is similar to the Dovonan Chamber and is designed for fragmenting munitions and solid rocket motors	Testing has been completed on HD projectiles (mustard agent) with a throughput of 9 projectiles/10 hour day	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Treatment is destruction via detonation	Donor explosives are required to treat the chemical munitions	Not designed for bulk propellants	Bulk propellants need to be burned and not detonated	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and treatment residues	N/A	N/A	N/A	N/A	Standard permitting of post-treatment units	Off-gases are converted to oxides of carbon via treatment with a cold plasma oxidizer resulting in minimal liquid residue condensate	Post-treatment of residues can be managed with a rinsate
Engineering controls	Ease of managing treatment technology and maintaining equipment	Minimal issues if treat the chemical munitions per unit design	N/A	N/A	40 % of the munition is treated with 60 % being the donor explosive	N/A	Technology understanding by the Army is for specific only for munitions at the Blue Grass and Pueblo Chemical Agent Destruction Pilot Plants	Development of mobile, semi-mobile or stationary units were reviewed in the "International Journal of Energetic Materials and Chemical Propulsion", DOI: 10.1615/IntJEnergeticMaterialsChemProp.2013005410, pages 447-461	N/A
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	Incineration-type technology requiring several acres that can meet the arc requirements	Site plan may be an issue with arc requirements	N/A	N/A	N/A	N/A	May require reactivation of a standby-by area	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Good	N/A	N/A	N/A	N/A	N/A	Applied research continues on this detonation chamber	N/A

Table 7. DDESB-APPROVED TECHNOLIGIES REVIEWD-EDS-Explosive Destruction System

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Not recommended for bulk propellants per Feb 2015 Army review since only one detonation can occur every other day per EDS.	A batch process treating 1.5 to 9 lbs. TNT equivalent (e.g., three, 4.2-inch mortars up to six, 4.2-inch mortars or ~14 lbs. single-base propellant) at a time depending on the design and retrofit	Containment vessel treating chemical munitions by external (implosion) detonation	N/A	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Treatment is destruction by external detonation	Only one detonation can occur every other day per EDS. Cutting charges are required to treat the chemical munitions	Not designed for bulk propellants	Bulk propellants need to be burned and not detonated	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and treatment residues	N/A	N/A	N/A	N/A	N/A	Containment vessel contains the blast, vapor and munition fragments. Ambient and direct plume monitoring is recommended. Treatment is confirmed by sampling residual liquid and air from the vessel prior to reopening the EDS.	N/A
Engineering controls	Ease of managing treatment technology and maintaining equipment	Minimal issues if treat the chemical munitions per unit design	N/A	N/A	The EDS is designed for mortars, shells, projectiles and bomblets	N/A	Technology understanding by the Army is specific only for munitions at the Sandia National Laboratories and Aberdeen Proving Ground Pilot Plants	Five transportable EDS units available through the Army	N/A
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	Incineration-type technology requiring several acres that can meet the arc requirements	Site plan may be an issue with arc requirements	N/A	N/A	N/A	N/A	May require reactivation of a standby-by area	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Good	N/A	N/A	N/A	N/A	N/A	Applied research continues on this detonation chamber	N/A

Table 8. TECHNOLOGIES UNDERGOING PILOT-SCALE TESTING-Actodemil ®-ARCTECH's Actodemil ® Treatment Technology

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	Definition	Specifics	-3	-2	-1	0	1	2	3
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	Propellant digestion requires strict parameter control	Two-step process of digesting the propellant and then neutralization-oxidation	Requires additional chemicals	Requires strict control of pH, alkalinity measure of resultant liquid, continuous circulation, strict temperature control and a minimum of 6 hours to treat for the elimination of the explosive properties	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Not demonstrated for variable propellant waste streams	Hot spots can occur during digestion if FOD tramp metal is present in the propellant waste stream	Propellant waste stream needs to be consistent to control digestion	Propellant containing chemicals using metal-based compounds will result in TCLP data for fertilizer above the reporting limits	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and TCLP metals in the fertilizer from metal-containing propellants	N/A	TCLP data for fertilizer made from a single-base propellant detected barium, chromium, and lead above the reporting limits	N/A	N/A	N/A	Nitrogen oxide gas is generated and treated with a wet scrubber to capture the off-gas	N/A
Engineering controls	Ease of managing treatment technology and maintaining equipment	Primary equipment is off-shelf items-mixers, pH control, propellant feed control, etc.	N/A	N/A	N/A	N/A	Basic off-the-shelf equipment requiring intrinsic safety requirements of AN9003 and OSHA 1910.307 Class and Divisions	N/A	N/A
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	3 acres per processing line (pounds of propellant treated per line depends on propellant type)	Site plan may be an issue with arc requirements	N/A	N/A	N/A	N/A	May require reactivation of a standby-by area	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Fair to Good	N/A	N/A	N/A	N/A	Applied research continues on this technology requiring a better understanding of treatment parameters	N/A	N/A

Table 9. TECHNOLOGIES UNDERGOING PILOT-SCALE TESTING-Decineration™ Rotary Furnace System

			Poorer than Status Quo			Equal to Status Quo	Better than Status Quo		
Criteria	**Definition**	**Specifics**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment	No testing of bulk propellants occurred	Low temperature (450 degree F) thermal demilitarization of ammunition ranging from small arms through 20 mm	N/A	N/A	N/A	N/A	N/A	N/A
Waste stream variability	How much flexibility and support is provided by each technology	Low temperature restricts treatment options	RD&D permit only allowed for treating fuzes, small mortars, primers, blasting caps, and grenades	Has not been tested with bulk propellants	Feed rate limit is 125 lbs./hr. for propellant; for gross weight feedrate is 550 lbs./hr.	N/A	N/A	N/A	N/A
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model	Off-gases and treatment residues	N/A	N/A	N/A	N/A	N/A	Off-gases are treated wit an afterburner/baghouse combination. Scrap metal and ash are also generated.	N/A
Engineering controls	Ease of managing treatment technology and maintaining equipment	Technology in the RD&D phase.	N/A	N/A	N/A	N/A	Final incinerator design is incomplete; however, the rotary furnace and ancillary equipment technology is well established	N/A	N/A
Layout possibilities	How much flexibility of site layout is possible without violating DOT and MIL-STD 286 tables	Incineration-type technology requiring several acres that can meet the arc requirements	Site plan may be an issue with arc requirements	N/A	N/A	N/A	N/A	May require reactivation of a standby-by area	N/A
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology	Fair to Good	N/A	N/A	N/A	N/A	N/A	Applied research continues on this technology requiring a better understanding of treatment parameters	N/A

Table 10. Weighted Decision Matrix - Which Waste Propellant Treatment Option is Best for Treating Propellant Containing Foreign-Object-Matter (FOD)?

Decision Factors		Status Quo (OBG)	HTO/SCWO	Donovan	APE 1236	SDC	DAVINCH	EDS	Actodemil ®	Decineration™ Rotary Furnace System
Criteria	Wt.	1	2	3	4	5	6	7	8	9
Safety hazards	3.0	0	-3	-3	-3	-3	-3	-3	-1	-3
Waste stream variability	2.0	0	-3	-2	-2	-3	-3	-3	-2	-3
Environmental releases	2.0	0	3	2	2	2	2	2	-2	2
Engineering controls	1.0	0	-3	3	3	3	-1	-1	1	1
Layout possibilities	1.0	0	2	1	2	2	2	2	2	2
Support	1.0	0	-2	0	2	2	2	2	1	2
Weighted Scores		**0.0**	-12.0	-5.0	-2.0	-4.0	-8.0	-8.0	-7.0	-6.0

Which waste propellant treatment option would be the best method for treating FOD-containing propellants?

The open burning (OB) of waste propellants has been practiced for many years in the in the United States; federal requirements for miscellaneous units are in 40 CFR 264.600-603 (Subpart X) and adopted by reference in 9VAC20-60-264 with other applicable requirements in 9VAC20-60-10 through 1505. In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonatable wave.

▶ **Winner: Status Quo**

Criteria	Definition
Safety hazards	Treatment of energetics and associated pre-treatment, treatment, and post-treatment
Waste stream variability	How much flexibility and support is provided by each technology
Environmental releases	Intermittent/quasi-instantaneous releases that are challenges to monitor and model
Engineering controls	Ease of managing treatment technology and maintaining equipment
Layout possibilities	How much flexibility of site layout is possible without violating Department of Transportation (DOT) and MIL-STD 286 arc tables
Support	How good is the support community at answering tough questions about using the alternative treatment technology, is the theme upgraded regularly to keep up with changes to OB technology

Note on calculation

The formula for weighted scores uses a Sumproduct formula and has conditional formatting applied. Please check that the formula and conditional formatting includes the correct cell ranges if you add or remove any rows or columns.

Instructions: Select and insert a score of **-3 to +3** for each criteria. The score will be multiplied by the weight to arrive at the total weighted score.
Keep the first column for **status quo** (i.e. no change) and score the options against the status quo.

Key:

1 Status Quo (OBG)-Open Burning Ground
2 HTO/SCWO-Hydrothermal Oxidation (HTO) or Supercritical Water Oxidation (SCWO) with Pretreatment
3 Donovan-Controlled Detonation Chamber (referred to as Donovan Chamber)
4 APE 1236-Deactivation Furnace APE1236 System
5 SDC-Static Detonation Chamber (SDC)
6 DAVINCH-Detonation of Ammunition in a Vacuum-Integrated Chamber (DAVINCH)
7 EDS-Explosive Destruction System (EDS)
8 Actodemil ®-ARCTECH's Actodemil ® Treatment Technology
9 Decineration™ Rotary Furnace System