



DEPARTMENT OF THE ARMY
HOLSTON ARMY AMMUNITION PLANT
4509 WEST STONE DRIVE
KINGSPORT, TN 37660-1048

REPLY TO
ATTENTION OF:

JMHS-CR

16 November 2016

SUBJECT: Request for March 2012 Report (ERDC/EL-12-8)
BAE SYSTEMS Ordnance Systems Inc. / Holston Army Ammunition Plant
4509 West Stone Drive, Kingsport
37-0028/ 568188

Mr. James P. Johnston, P.E.
Deputy Director, Permitting and Regulatory Development
Tennessee Department of Environment and Conservation
Division of Air Pollution Control
William R. Snodgrass Tennessee Tower, 15th Floor
312 Rosa L. Parks Avenue
Nashville, TN 37243

Dear Mr. Johnston,

In a letter to BAE SYSTEMS Ordnance Systems Inc., dated September 21, 2016, you requested an opportunity for the Division of Air Pollution Control (DAPC) to review a report titled "Alternative Treatment Options for Open Burning of Explosive Waste at Holston Army Ammunition Plant", dated March 2012. Since the document requested was a U.S. Army document, BAE SYSTEMS Ordnance Systems Inc. referred your request to Holston Army Ammunition Plant (HSAAP) for review and release.

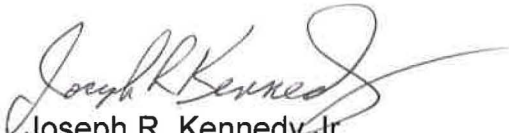
The US Army Corps of Engineers, Engineer Research and Development Center (ERDC) prepared a report titled "Alternative Treatment Options for Open Burning of Explosive Waste at HSAAP" for the Program Manager, Joint Services, U.S. Army Research, Development and Engineering Center (ARDEC). The document has a distribution statement that limits distribution to U.S. Government agencies only. Therefore, release of this document to a state agency required receiving approval to release from ARDEC and Project Director, Joint Services (PD JS) and the supporting legal offices.

As you may be aware, the Army is subject to the Freedom of Information Act, 5 U.S.C. § 552, which protects from release trade secrets and commercial or financial information obtained from a person that is privileged or confidential. Release of such information without permission could subject the Army to litigation. Therefore, ARDEC and PD JS have consented to release of the requested document to TDEC for review, with the exception of Appendix A: Vendor White Papers, which contains privileged and confidential vendor information. In addition, portions of the report that reflect privileged and confidential information from vendors was required to be redacted. Redactions are clearly identified within the document with a series of X's.

It is important to highlight the enclosed PD JS memorandum that accompanies the release of the requested 2012 ERDC report. This memorandum details the objectives and limited scope of the 2012 ERDC report and notes that the report was completed prior to changes in the Department of Defense Explosive Safety Board (DDESB) guidance and Title V Permit Renewal application which resulted in more stringent emissions regulations. Most importantly, the PD JS memorandum points out that there is still a need for a more detailed study specific to HSAAP needs and Resource Conservation and Recovery Act permitting requirements. A more detailed study is ongoing and is anticipated to address any safe and practical treatment options for explosive waste at HSAAP.

The Point of Contact for this action is Laura Peters@ 423-578-6193.

Sincerely,


Joseph R. Kennedy Jr.
Commander's Representative

2 Encls

ERDC-2012 -Rpt without vendor info

Signed HSAAP-TDEC-Release of 2012 ERDC RPT 11-04-2016



REPLY TO
ATTENTION OF

DEPARTMENT OF THE ARMY
PROJECT DIRECTOR JOINT SERVICES
1 BUFFINGTON ROAD
PICATINNY ARSENAL NJ 07806-5000

NOV 23 2016 PM12:04

SFAE-AMO-JS

4 November 2016

MEMORANDUM FOR Armaments Research Development and Engineering Center (ARDEC)
Legal Office, (RDAR-DGC/Mr. Larry Brady)

SUBJECT: Release of the March 2012 Engineer Research and Development Center (ERDC)
Report "Alternative Treatment Options for Open Burning of Explosive Waste at Holston Army
Ammunition Plant (HSAAP), March 2012"

1. This memorandum is to accompany and supplement the release of the March 2012 ERDC Report "Alternative Treatment Options for Open Burning of Explosive Waste at HSAAP," sponsored by the Office of the Project Director Joint Services. The distribution for this report is currently authorized to U.S. Government agencies only, thus prompting this action to release it to the Tennessee Department of Environment and Conservation, which is not a U.S. Government agency.
2. The objective of the above cited 2012 report was to review the status of alternative explosive hazardous waste disposal technologies as an aid in monitoring the progress of the ongoing development of safe alternatives to open burning of explosive hazardous waste at HSAAP. The report assessed these five different technologies: Alkaline Hydrolysis, Static Detonation Chamber, Incineration, Gas Phase Reduction, and Supercritical Water Oxidation with the primary focus of treating open burning waste.
3. The report discussed the application, general safety and engineering controls, waste stream, and capital and operating costs for each option. The report estimated wastes generated onsite and burned in open pans from the years 2000 to 2009. The ERDC report was completed prior to changes in the Department of Defense Explosives Safety Board (DDESB) guidance and prior to Title V Permit Renewal Application (applied for in Dec. 2013) which resulted in more stringent emissions regulations.
4. The report, subsequently finalized in 2012, provided a limited survey of technologies available in 2010. The conclusions in the report were based on generalities and did not consider the specific and detailed compositions of the waste streams at HSAAP. In addition, the report did not provide a full explosive safety analysis for processing, handling, treatment and post operation cleanup for the explosive hazardous waste generated at HSAAP.

SAFE-AMO-JS

SUBJECT: Release of the March 2012 Engineer Research and Development Center (ERDC) Report "Alternative Treatment Options for Open Burning of Explosive Waste at Holston Army Ammunition Plant (HSAAP), March 2012"

5. The full objective of this study has not yet been met. There is still a need for a detailed waste stream analysis as well as documentation for technology specific explosive safety requirements before selection of a safe and appropriate treatment technology, that meets both HSAAP needs and the Resource Conservation and Recovery Act permitting requirements, can be made. In addition none of the technologies were reviewed for application at HSAAP by the US Army Technical Center for Explosives Safety (USATCES), the primary Army agency for explosives safety. As a result, the Army is continuing towards the initial study objective and will supplement the 2012 findings with additional waste classification analysis and technologies assessments. The results of this ongoing study will provide a comprehensive approach, realistically incorporating the waste stream and safe handling specifics to match the correct technology with the correct waste stream. At the conclusion, a decision will be made regarding the best alternative treatment options for open burning of explosive waste at HSAAP.

6. This office concurs with the appropriate release of the Report "Alternative Treatment Options for Open Burning of Explosive Waste at Holston Army Ammunition Plant (HSAAP)," March 2012, except for Appendix A: Vendor White Papers, which contains proprietary vendor information. The Project Director Joint Services point of contact is Dr. Gabriela Dory, SFAE-AMO-JS, 973.724.5746, gabriela.a.dory.civ@mail.mil.


Matthew T. Zimmerman
Deputy Project Director Joint Services

ERDC/EL TR-12-8

Environmental Laboratory



**US Army Corps
of Engineers®**
Engineer Research and
Development Center

Alternative Treatment Options for Open Burning of Explosive Waste at Holston Army Ammunition Plant

March 2012

Alternative Treatment Options for Open Burning of Explosive Waste at Holston Army Ammunition Plant

Final report

Distribution authorized to U.S. Government agencies only; proprietary information; March 2012. Requests for this document must be referred to Environmental Technology Group (ARDEC/Donald Yee), Building 172, Picatinny Arsenal, NJ 07806-5000.

Prepared for RDECOM-ARDEC

Under A1040-MODERNIZATION OF INDUSTRIAL BASE

Abstract

Production of potentially dangerous explosive or explosives-contaminated waste materials is inherently linked to the production of explosives. These waste materials are most safely disposed of by an onsite decomposition method, and current best practice is an open burning method. As the Army industrial base modernizes, though, the environmental effects of open burn processes have come under greater scrutiny. Efforts to identify and demonstrate alternative explosive waste disposal technologies at Army ammunition plants have been underway for at least 40 years. This report delineates the current state of practice for alternative disposal options with reference to possible application at Holston Army Ammunition Plant (HSAAP). The objective is to compare commercially available disposal technologies in the event that open burning becomes environmentally or financially unfeasible for application at HSAAP. Incineration technologies remain the most certain, safe, and cost-effective method for explosives waste disposal. Given the prospect of regulatory issues, though, incineration is not viable. Supercritical water oxidation (SCWO) technologies are rapidly developing, and are a viable option for possible future installation. The specific properties of the static kiln that make it a good option for assembled munitions disposal lead to extra capital costs. Otherwise, a static kiln is a viable option. Alkaline hydrolysis and gas phase chemical reduction (GPCR) processes are not applicable to the full range of wastes generated by HSAAP. As HSAAP moves forward, the highest level of confidence for successful replacement of open burning that may be expected is with SCWO technology, followed by static kiln technology.

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Preface

This report was prepared for the Program Manager, Joint Services, U.S. Army Research, Development and Engineering Center, Picatinny Arsenal, NJ. It includes the results of Work Unit A1040, Modernization of Industrial Base. The research was conducted by the U.S. Army Engineer Research and Development Center (ERDC)-Environmental Laboratory (EL), Vicksburg, MS, under the sponsorship of the U.S. Army Armament, Research, Development and Engineering Center (ARDEC), Picatinny Arsenal and the U.S. Army ARDEC Program Executive Office for Ammunition, Heavy Metals Office, Picatinny Arsenal.

This project was performed under the general supervision of Dr. Elizabeth Ferguson, Technical Director, Military Munitions in the Environment (MME), EL, and Dr. Steve L. Larson, Lead Principal Investigator, EL. In-house review was provided by Robert McComas and Jose Mattei-Sosa, Environmental Engineering Branch (EP-E), EL.

This study was conducted under the direct supervision of W. Andy Martin, Branch Chief, EP-E, and under the general supervision of Warren Lorentz, Division Chief, Environmental Processes and Engineering Division (EPED), and Dr. Elizabeth C. Fleming, Director, EL.

At the time of this study, COL Kevin J. Wilson was ERDC Commander. Dr. Jeffery P. Holland was ERDC Director.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms

1 Disposal of Explosive and Explosives-contaminated Waste at the Holston Army Ammunition Plant

The Holston Army Ammunition Plant (HSAAP) is a manufacturer of military explosives located in Kingsport, TN. The facility was constructed in 1942, and has remained in continuous operation since then. It is currently operated under contract with the Department of Defense (DoD) by BAE Systems, Inc. HSAAP manufactures hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine (HMX), along with smaller quantities of other explosives.

Production of potentially dangerous explosive or explosives-contaminated waste materials is inherently linked to the production of explosives. These waste materials are most safely disposed of by an onsite decomposition method. Remaining onsite minimizes the safety and security risks associated with transportation, and complete decomposition of the energetic material permanently neutralizes the explosive risk associated with these waste materials. Currently, the best practice is an open burning (OB) method, and the HSAAP operates an OB area in compliance with hazardous waste permit TNHW-148 issued by the Tennessee Department of Environment and Conservation (TDEC), and most recently renewed 31 March 2011 (TDEC 2011). Under the terms of this permit, HSAAP may dispose of 5,000 lb net explosive weight per day in a designated open burn area.

Open burn procedures are a proven method to safely dispose of explosive and explosives-contaminated wastes. As the U.S. Army industrial base modernizes, though, the environmental effects of open burn processes have come under greater scrutiny (Cropek et al. 1998). Efforts to identify and demonstrate alternative explosive waste disposal technologies at Army ammunition plants have been underway for at least 40 years (Pinkerton et al. 1979). This report delineates the current state of practice for alternate disposal options with reference to possible application at HSAAP. The objective is to compare commercially available disposal technologies in the event that OB becomes environmentally or financially unfeasible for application at HSAAP.

Current practice

Three broad categories of solid waste are disposed of using OB methods on the grounds of HSAAP: (1) 'burn pan' or 'pan' waste, (2) 'cage' waste, and (3) 'pile' waste.

The first category is referred to as 'burn pan' or 'pan' waste, and consists of bulk raw explosives that have become contaminated through contact with the manufacturing floor, or out-of-spec product unsuitable for resale or re-crystallization. Each production building accumulates pan waste in marked containers for weekly disposal. The majority of the pan waste is shoveled out of the building catch basins into plastic bags. No more than 20 lb of explosive is placed into a single bag. Operators at each building fill out paperwork detailing the source and weight of the waste material, and material handlers remove the explosive waste to the burn ground each Wednesday during normal operations.

The burn pan unit consists of four steel pans in a diked enclosure secured by chain link fencing with a locked gate (Figure 1). The pans are roughly 3 ft wide, 20 ft long, less than 1 ft deep, and are filled level with soil to provide a heat-absorbing burn surface. Each pan has a cover that normally remains locked over the pan and is rolled away for loading or burning.

Solid waste is brought to the burn pans each Wednesday by the materials handling division. The burn pan cover is first unlocked and rolled away, and plastic drop-cloth material is placed over the soil liner of the pan. Plastic bags containing explosive waste are placed on the plastic liner, cut open, and poured out. The empty plastic bags are removed to the burn cages as cage waste. Explosive waste is spread out evenly to a depth of no greater than 3 in. on the surface of the pan and left to dry. To facilitate drying, the pan covers are replaced in inclement weather.

Plant personnel indicated that burning usually takes place on Friday. To initiate a burn, a 3- to 4-ft coiled paper wick is placed in the material and allowed to drape over the side of the pan to the ground. The wick is lit by remotely activating an electric resistive coil lighter placed on the end of the wick. Under current regulatory limits, each pan may burn up to 1,500 lb of raw explosive at one time, with a total burn limit (for the four-pan unit) of 5,000 lb at one time.



Figure 1. HSAAP open burn area.

The total weight of explosive pan waste generated per year over the period 2000-2009 is summarized in Figure 2. The amount of yearly disposed waste has increased as a result of increased material production and ongoing efforts to permanently dispose of unusable stockpile material. A yearly average in the range of 120,000-150,000 lb of pan waste is expected over the next five years.

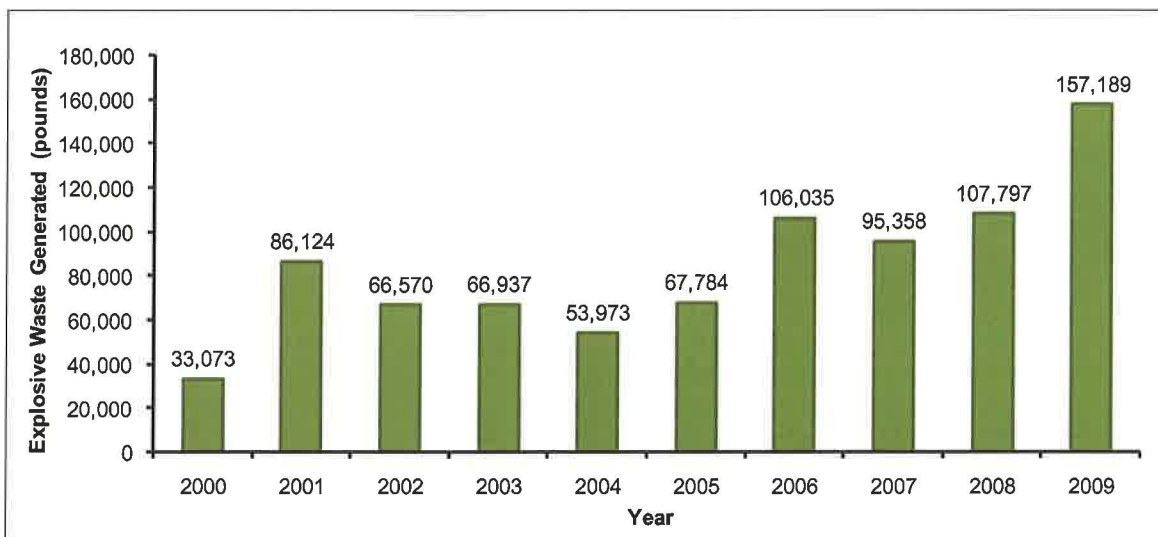


Figure 2. Explosive waste generated onsite and burned in open pans at HSAAP.

The second category of solid waste is known as 'cage' waste. Cage waste consists of explosives-contaminated small articles such as plastic bags, paper towels, false bottom filters from re-crystallization tanks, and dewatering filter socks. This material is placed in a steel cage adjacent to the burn pan area and is generally burned once a week.

The third category of solid waste is known as 'pile' waste. Pile waste is the general term for large articles that may be contaminated with solid explosives. This encompasses construction material, piping from decommissioned buildings, and soil removed from under raised walkways. These materials are placed in a large pile adjacent to the burn pan area and burned off once a year or as needed. The goal of the burn is to achieve 5X decontamination of the steel pieces for recycling purposes. To confirm decontamination, burn monitoring is performed by infrared camera. Following confirmation of the burn temperature, contractors remove the steel components for recycling.

Future prospects

HSAAP expects approximately 120,000-150,000 lb net explosive weight per year requiring disposal in the burn pans over the next five years. This number also contains nonconforming plastic bonded explosives (PBXs), which may be decreasing as production of insensitive munitions (IM) formulations, such as IMX-101, increases. The total waste associated with IM production remains unknown at this time.

Initiation of the Reverse Osmosis (RO) industrial wastewater treatment system at Building E-7 will result in an additional 60-70 lb per day of RDX solids requiring disposal. Weekly wet vacuum removal of RDX from the catch basins following RDX dewatering operations will add additional waste solids. The amounts are unknown at this time, but may be estimated from the difference in RDX entering and leaving the catch basins at a known flow rate.

Estimates for solid waste may change depending on the disposition of current practices for ammonium nitrate solution (ANsol). ANsol is a necessary byproduct of explosive compound nitration, both for RDX/HMX production and insensitive munitions formulation production. Past practice included selling ANsol to Eastman Chemical Corp., though this was discontinued by 2006 due to environmental considerations. From 2007 to the present, ANsol has been repurposed for mining explosives formulations. Other repurposed applications for ANsol, such as fertilizer

usage, are unfeasible since the product contains up to 1% RDX by weight. The single application available for ANsol byproduct carries a risk of reduced demand, which would leave no other options than disposal of ammonium nitrate as a listed waste (Resource Conservation and Recovery Act (RCRA) designation K044). Under RCRA regulations HSAAP can only hold this waste for 90 days. Several years ago, the estimated cost for disposal of the ANsol was \$2.50 per pound.

Alternative disposal options

Each of the three classified waste streams at HSAAP has distinct physical characteristics. This makes it unlikely that a single disposal system will be suitable for all three streams. This report assesses a range of commercially available options with a primary focus on disposing of burn pan waste and a secondary focus on disposing of the other waste classes. This will put greater emphasis on the largest waste stream with considerations for the remaining waste. Each possible approach was evaluated in terms of safety, versatility, energy requirements, process economics, and environmental outputs.

The three broad classes of technology available to dispose of solid explosive wastes are chemical oxidation, chemical reduction, and thermal oxidation processes. The commercially available processes within these classes include:

1. Alkaline hydrolysis – A process that combines a caustic solution with the munitions in an agitated reactor to decompose the explosive material.
2. Static Detonation Chamber – A closed chamber deflagration process developed for demilitarization applications.
3. Incineration – A process that uses deflagration, most commonly in a rotary kiln or fluidized bed configuration.
4. Gas Phase Chemical Reduction (GPCR) – A process that incorporates hydrogen as a chemical reductant at high temperature to decompose organic compounds.
5. Supercritical Water Oxidation (SCWO) - A high-temperature, high-pressure technology used to destroy organic compounds through oxidation.

Each of these technologies is sold commercially, and technology demonstration or full-scale operating data are available. Information from process vendors and public literature was used in analyzing this option. The following sections provide technology profiles for each of the available processes, with a summary of findings and recommendations.

2 Alkaline Hydrolysis

Process description

Alkaline hydrolysis is a proven process for the disposal of bulk explosives. The alkaline hydrolysis reaction “decomposes the explosive to organic and inorganic salts, soluble organic compounds and various gases” (Larson et al. 2007). A pilot demonstration of this technology was completed on the grounds of HSAAP (Bonnett and Elmasri 2002), and forms the basis of this analysis. Alkaline hydrolysis provides flexible process rates, equipment selections and scaling, and has a 99.9% destruction rate efficiency.

A process flow diagram of alkaline hydrolysis is provided in Figure 3. The reactor pH is controlled by introducing caustic into the process water in the reactor. This caustic process solution is heated to approximately 90°C, and the energetic materials are added to the reactor using a solid feed system. The required hold time for complete hydrolysis of solid explosives is several hours, though at completion the remaining solution may be pH adjusted and reused for further energetic solids additions. Effluent hydrolysate must be neutralized to a pH below 9 using sulfuric acid or nitric acid before release to a holding tank for post-treatment processing.

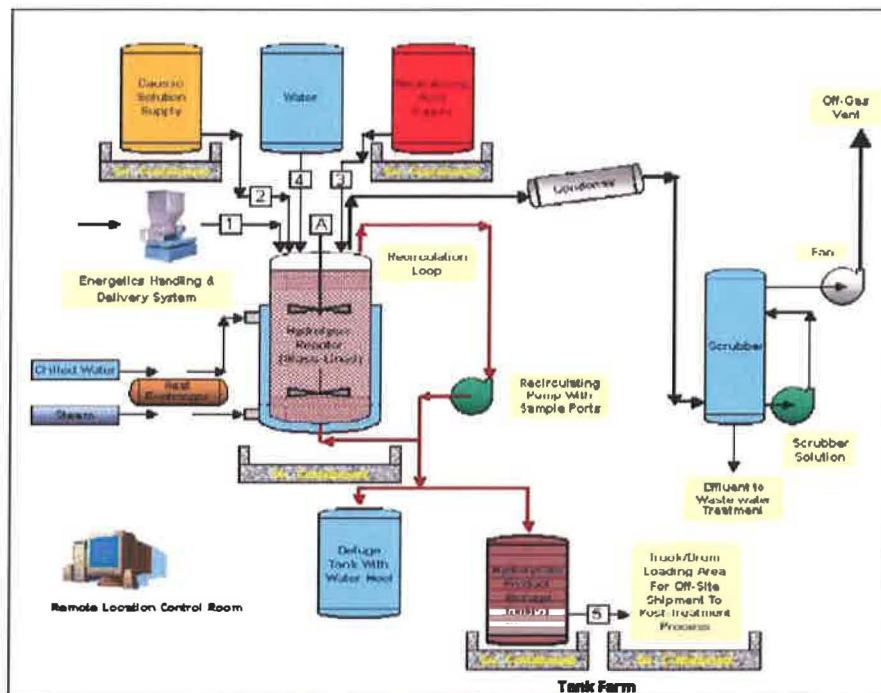


Figure 3. Alkaline hydrolysis process schematic.

Caustic treatment is suitable for decomposition of bulk explosives, though a stirred tank setup is not suitable for processing contaminated cage waste articles. This option is also not suitable for ANsol disposal, and the technology has not been demonstrated for PBX or IMX formulations. It remains an option solely for decomposition of bulk loose explosives.

Current applications

Hot caustic soda treatment is currently being used at Radford Army Ammunition Plant to destroy solid propellant wastes. A test treatment of base hydrolysis for destruction of energetic materials was conducted at HSAAP and reported by Bonnett and Elmasri (2002, Special Publication ARWEC-SP-01001). Alkaline hydrolysis has also been demonstrated for the decomposition of assembled aluminum body munitions (Wong 2011).

Safety profile/engineering controls

The storage and use of strong caustic solution would be an ongoing safety concern, requiring the implementation of engineering controls and proper handling procedures. Caustic soda (sodium hydroxide) can be purchased in solid or liquid form. A XXX solution of caustic soda will raise the pH of water above pH 14. Handling and exposure risks are reduced by using liquid caustic soda. Chemical feed pumps can be used to introduce caustic soda into the alkaline treatment tank limiting worker exposure. Bulk liquid caustic soda can be purchased in drums or by tanker. As long as there is limited exposure to air, the caustic soda can be stored for long periods of time. HSAAP operators in the production area are trained in handling strong acids and bases. Therefore personal protection equipment (PPE) falls under their normal operation procedures for this technology. All process controls must be explosion-proof. The required systems include pH, temperature, tank level, and tank mixing controls with real-time off-gas analysis as an additional environmental monitoring step.

Waste streams

The off-gas created from the hydrolysis reactor may be treated using an off-gas treatment system. The gas is sent through a condenser and then to a scrubber system before venting to the atmosphere. This ensures that no toxic chemicals are released to the atmosphere.

Following neutralization, effluent hydrolysate created from the reaction is suitable for biological post-treatment at the existing industrial wastewater treatment plant (Felt et al. 2007).

Capital and operating costs

A hot caustic reactor requires the use of sodium hydroxide. The maximum theoretical pH of sodium hydroxide is greater than pH 14. The assumptions used for estimating quantity of hydroxide required depend on the hydroxide concentration in the tank, its repeated reuse stability with time, and the amount of solid residue in the tank. The pH of the fluid in the tank should remain high over multiple loadings requiring low quantities of additional sodium hydroxide to maintain treatment pH.

Pfautler Reactor Systems provided an estimated cost for building a system similar to the one reported by Bonnett and Elmasri (2002):

Based on the capacities and flow rates referenced in the article on the previous system, a similar size system would be required to handle the XXX lbs/year capacity, as we had earlier discussed by phone.

If we were to provide a similar system, XXX gallon size glasslined reactor with mixer and accessories, with PLC control system, all mounted on a structural steel skid with interconnecting piping, the rough budget price would be XXX and delivery would be about XXX weeks.

XXX [XXX@robn.com] ref 11R70040

The estimated chemical and labor costs are listed in Table 1. The system requires two operators per day. This estimation is based on a feed rate of XXX lb/hr for 4 hr and one operator for an 8-hr shift. The estimated annual caustic soda cost is based on XXX w/w concentration in the reactor with refilling the tank on a weekly basis with an annual usage of XXX lb of XXX sodium hydroxide. HSAAP has waste nitric acid streams available for neutralization. Therefore neutralization should not be a factor. The annual hydroxide costs are approximately XXX given 2011 prices for XXX caustic solution. Given the capital and operating cost estimates, the 10-year present cost of disposal operations with an alkaline digestion system may be estimated using a discount rate of XXX (Office of Management and Budget (OMB) 2010). By this estimate, the 10-year present cost of operating an alkaline digestion unit is approximately XXX.

Table 1. Estimated annual chemical and labor cost for hot caustic hydrolysis system.

Chemical Cost	lb/yr	\$/lb	\$/year
NaOH (50% w/w) (caustic soda)	XXX	XXX	XXX
Waste nitric acid available at HSAAP	-	-	
Annual chemical costs			XXX
Operating Labor Cost (C_{OL})			
Operators per Day	\$/hr	d/yr	\$/yr
XXX	XXX	XXX	XXX
Miscellaneous Labor (XXX_{OL})			XXX
Yearly Maintenance (XXX_c) (C_c=XXX)			XXX
Estimated Annual Operating Costs			XXX

3 Static Detonation Chamber

Process description

A static detonation chamber (SDC) is a detonation-safe, double-walled chamber designed to destroy assembled munitions and bulk explosives by deflagration. Detonation chambers have been developed for several demilitarization applications, and their ability to meet demil requirements leads to waste disposal applicability. The Dynasafe Mobile SDC 1200M Munitions Detonation Chamber (Figure 4) is a commercially available version of this technology. The 'static' descriptor is associated with the lack of explosive counter-charges to initiate destruction. Rather, heat from explosives in process provides the necessary operating temperature. Electrical resistive coils heat the chamber during startup to begin the deflagration process. As a result of the internal heating/deflagration design, the majority of explosives are decomposed without detonation.

Standard operating temperature within the chamber is 550-600 °C, and the chamber (Figure 5) is designed for detonation pressures equivalent to 1 kg of TNT with a 100% margin of safety. The inner chamber contains an additional enclosure that provides a 100% backup, while the outer chamber has a thermally insulated cover. The inner and outer chambers are separated by an air space containing electric resistance heaters. This serves to "decouple detonation stresses from the inner to the outer chamber" (UXB International, Inc. 2010) and supply heat. The chambers are surrounded by a dust enclosure.

The SDC is capable of decomposing any energetic or contaminated article that can be placed in a cardboard box. This would include bagged explosives (pan waste), all cage waste articles, and possibly pile waste articles with appropriate size reduction. Productivity statements provided by UXB International indicate that an SDC 1200 can be expected to process on the order of XXX lb net explosive waste per 10-hr operating shift. This estimate is based on operating data from assembled munitions destruction where the net explosive waste disposal ranged from XXX lb per shift to XXX lb per shift. In theory, ammonium nitrate solids are suitable for deflagration disposal in an SDC, although the approach has not been demonstrated.

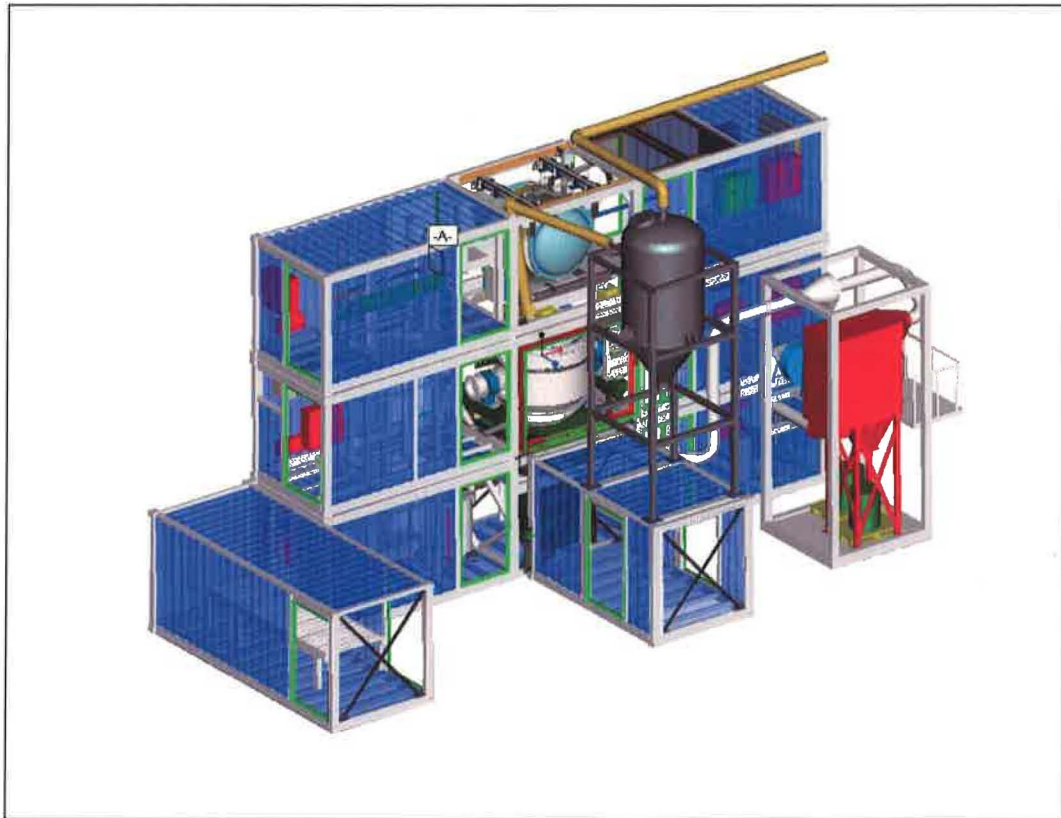


Figure 4. Dynasafe SDC 1200M (UXB International 2010).

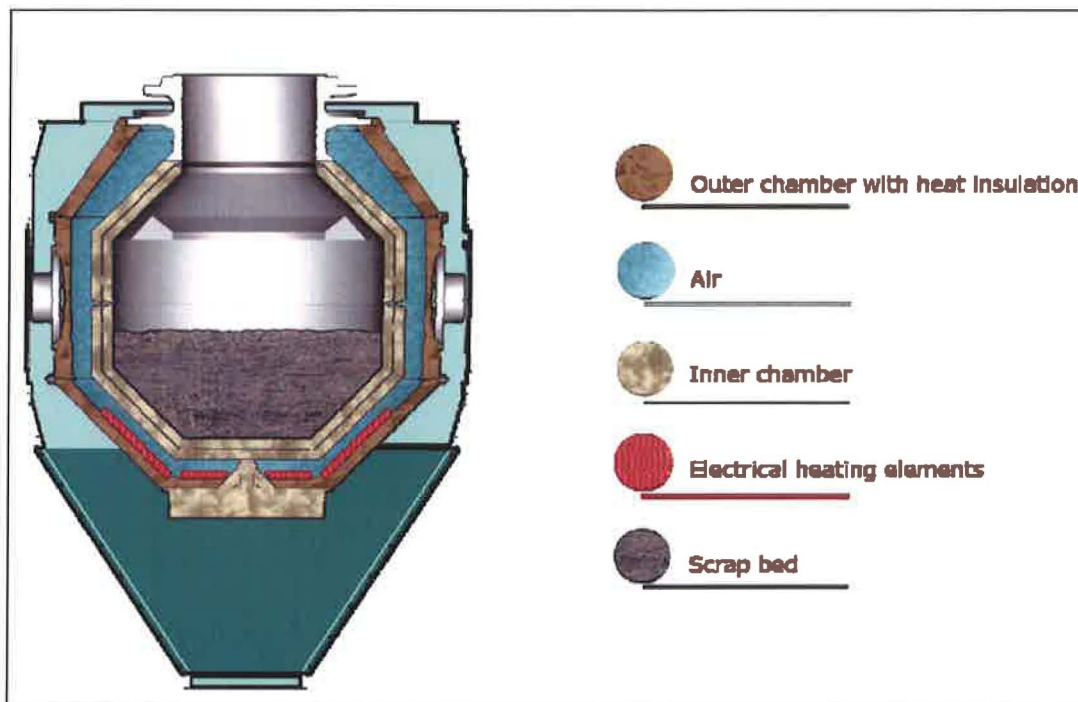


Figure 5. SDC 1200M cross section through chamber (UXB International 2010).

Current applications

Dynasafe SDCs have been in use since 1997 with nine units deployed and no reported explosions or accidents. Current permits in the United States are Anniston, AL (Staggs 2011), and Camp Minden, LA. Air quality permitting for both units required 10 months or less.

Safety profile/engineering controls

An SDC-1500 for HSAAP will require liquid flashback protection along the line with several discrete feed pumps. The system will have a secondary combustion chamber that will be electrically heated, a spray dryer using process heat, and NO_x scrubbers that will need to be replaced every 5- 10 years depending on the NO_x loading.

Waste streams

Gaseous combustion products are treated by an included treatment system. The treatment train includes cyclone particulate removal, oxidation with fast quench, dry scrubber, and NO_x removal. Some solid scrap material remains in the chamber to act as a heated bed, although once the chamber reaches XXX capacity, the scrap is removed for recycling.

Capital and operating costs

An SDC-1500 detonation system costs approximately XXX. It is estimated that a schedule of one shift per day with two operators can burn approximately XXX lb of RDX per year. Additional loading will require two shifts for short durations until the excess can be destroyed. The power requirement for the SDC-1500 will be XXX kW when not running and potentially higher when on standby. The estimated annual operating costs are listed in Table 2. The system requires two operators per shift per day. This estimation is based on a feed rate of XXX kg/hr and 8-hr shifts (XXX kg/d). Given the capital and operating cost estimates, the 10-year present cost of disposal operations with a static kiln system may be estimated using a discount rate of XXX (OMB 2010). By this estimate, the 10-year present cost of operating an alkaline digestion unit is approximately XXX.

Table 2. Estimated annual labor costs for detonation chamber.

Operators per Day	\$/hr	d/yr	\$/yr
XXX	XXX	XXX	XXX
XXX	XXX	XXX	XXX
Miscellaneous Labor (XXX _{oL})			XXX
Yearly Maintenance (XXX _{Cc}) (C _e =XXX)			XXX
Estimated Annual Operating Costs			XXX

4 Incineration

Process description

Incineration is a proven method for destroying munitions with a 99.99% destruction rate efficiency. Many types of incinerators exist, although the rotary kiln (Figure 6) and the fluidized bed (Figure 7) are the most common (North Atlantic Treaty Organization (NATO) 2008). The incineration process uses deflagration to break down the munitions, which is followed by a pollution abatement system to treat gaseous combustion products.

The rotary kiln typically operates at temperatures between 1,100 and 1,300° C. These high temperatures enable a more complete combustion reaction. The rotary kiln system includes the feed system, kiln chamber, and afterburner. The waste enters the kiln through the feed system and flows due to the slope and rotation of the kiln chamber. The length of the kiln and speed of rotation control how well the waste mixes with the combustion air. Rotary kilns are fueled by natural gas, oil, or pulverized coal.

Fluidized bed incinerators (Figure 7) are a more recent development for energetics disposal with some advantages over rotary kilns for the destruction of bulk explosives (van Ham 1998). The thermal bed mass inside the incineration vessel is a bed of noncombustible solid particles that provides a uniform bed temperature. The fluidized bed operating temperature depends on the type of material used in the bed, but typical operating ranges are between 750 and 1,110°C. The freeboard space above the bed, however, typically runs 50°C higher than the bed. Combustion air is introduced into the vessel through a plenum under the bed. The fluidized bed is incinerated by combustion with fossil fuels. As with the rotary kiln, heat transfer is an important part of the incineration process. In the fluidized bed, the bed transfers heat to the waste material and the waste material and fuel return the heat to the bed.

Rotary kiln incinerators are suitable for disposal of all wastes at HSAAP, though pile waste would require considerable size reduction. Fluidized bed incinerators are suitable for disposal of bulk explosives and ammonium nitrate solids. Cage wastes may be disposed of in a fluidized bed following size reduction by shredding.

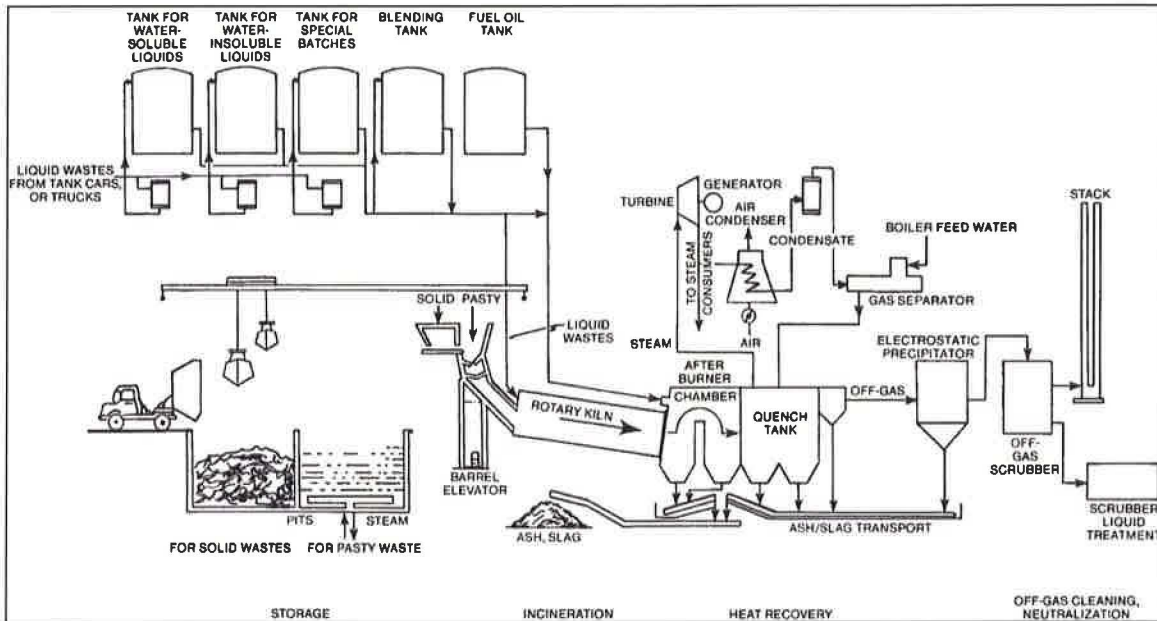


Figure 6. Typical rotary kiln for municipal solid waste.

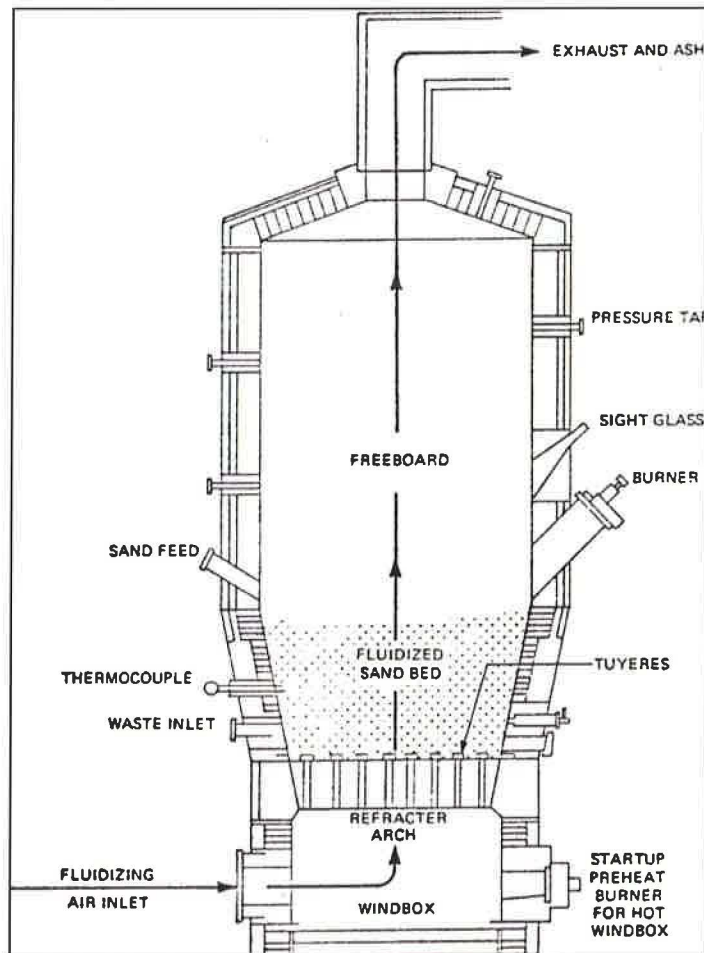


Figure 7. Cross section of a fluidized bed incineration vessel.

Current applications

Incineration is a well-established, mature technology for explosives destruction (NATO 2008). The U.S. Army operates demilitarization incinerators for small assembled munitions, including a rotary kiln model, APE-1236 (Department of the Army 1982). Fully permitted rotary kiln incinerators are operated at Tooele Army Depot, Utah; McAlester Army Ammunition Plant, Oklahoma; and Lake City Army Ammunition Plant, Missouri (Seltzer et al. 2001). The most recently permitted rotary kiln application is installed at Picatinny Arsenal, NJ (New Jersey Department of Environmental Protection 2011).

Safety profile/engineering controls

Explosives waste incineration is a standard Army process governed by accepted procedures (Department of the Army 1982). Bulk explosives are fed to incineration processes as 25% water slurry to prevent detonation.

Waste streams

Standard waste streams for incineration applications include scrap material, flyash, and gas. Scrap will be minimal in the proposed application. Flyash from this incinerator would be RCRA hazardous waste requiring proper disposal. The gaseous waste stream requires downstream pollution control equipment. Current applications have been permitted as hazardous waste incinerators. The most recent application in New Jersey required 10 years to gain regulatory acceptance, and future permits applications may expect resistance from regulatory agencies (Robillard 2011).

Capital and operating costs

The estimated annual operating costs are listed in Table 3. The system requires one operator shift per day. Heat in the furnace is maintained by natural gas. Given previous cost estimates of rotary kiln installation (Wolf 1995) and standard modification by the chemical engineering plant cost index, the capital cost of a rotary kiln installation is estimated at XXX. Given the capital and operating cost estimates, the 10-year present cost of disposal operations with a rotary kiln system may be estimated using a discount rate of XXX (OMB 2010). By this estimate, the 10-year present cost of operating a rotary kiln unit is approximately XXXM.

Table 3. Estimated annual costs for an incineration system.

Utilities		\$/month	\$/year
Natural Gas		XXX	XXX
Electricity		XXX	
Operating Labor Cost (C_{OL})			
Operators per Day	\$/hr	d/yr	\$/yr
XXX	XXX	XXX	XXX
Miscellaneous Labor (XXX_{OL})			XXX
Yearly Maintenance (XXX_{Cc}) (C_c=XXX)			XXX
Estimated Annual Operating Costs			XXX

5 Gas Phase Chemical Reduction

Process description

Gas phase chemical reduction (GPCR) is a non-flame process that utilizes hydrogen to create a strongly reducing environment for the decomposition of organic wastes. A block flow diagram of the process is provided in Figure 8. Rather than an ideal oxidation product of CO₂, a reductive process has an ideal end point of methane for organic compounds. Nitrogen compounds present in a strongly reducing environment may be expected to form nitrogen gas and ammonia. The GPCR reaction vessel operates at temperatures above 850°C. Non-volatile dunnage items are decontaminated in a thermal reduction batch processor lying outside of the GPCR main reactor.

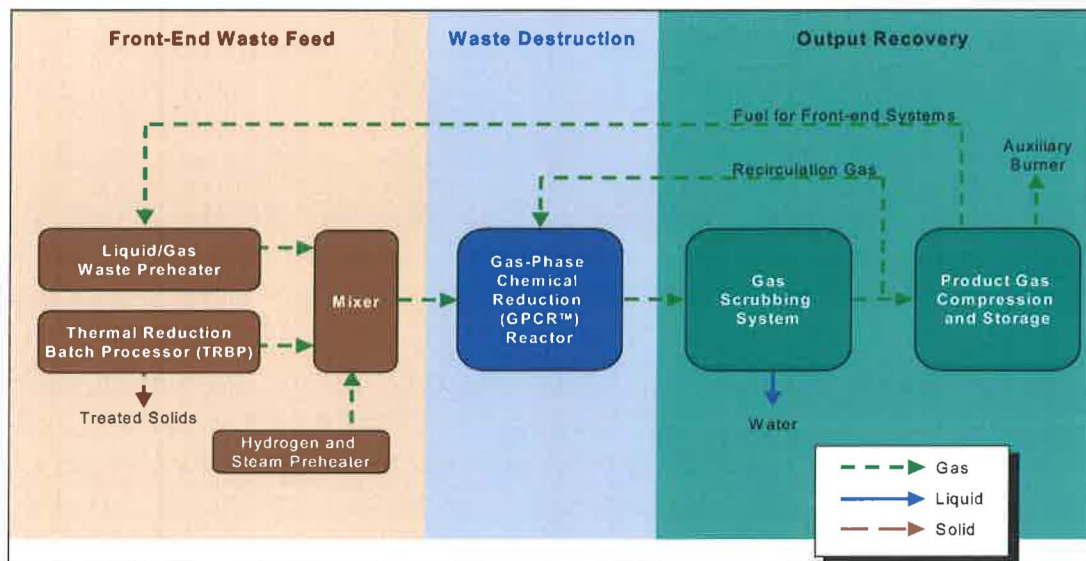


Figure 8. Block flow diagram of gas phase chemical reduction (GPCR).

The vendor supplied white paper references unpublished testing of GPCR to reduce small quantities of explosives and propellants associated with shell casings at Edgewood Research, Development and Engineering Center (ERDEC). GPCR has also been tested for decontamination of assembled chemical weapons dunnage material (National Research Council (NRC) 1999).

The main bottleneck in GPCR processing is transforming solid phase explosives to gas phase or aerosolized states for treatment (Schwinkendorf et al. 1997). The treatment reaction occurs in the gas phase, so waste streams are vaporized before introduction to the GPCR processor, atomized directly into the processor, or thermally desorbed prior to introduction to the processor. The technical feasibility of decomposing bulk explosives with this application has not been demonstrated.

Current applications

GPCR technology has been applied to organic waste streams including polychlorinated biphenyls (PCBs) and chlorinated solvents in the commercial sector. The Department of the Army has investigated GPCR as part of an assembled chemical weapon demilitarization technology package (NRC 1999). The process vendor makes reference to an unpublished demilitarization project for the thermal desorption/GPCR treatment of neat quantities of explosives on shell casings. To the authors' knowledge, the safety and efficacy of GPCR for bulk explosives has not been demonstrated.

Safety profile/engineering controls

The safety of introducing bulk explosives into a GPCR has not been demonstrated. Standard solids handling procedures for this application include a thermal desorption unit operating under nitrogen atmosphere. Under reducing conditions, deflagration of the waste stream is not a major risk, but the detonation potential of the system is not known.

Waste streams

Gaseous waste streams from the GPCR processing unit include methane, CO₂, N₂, ammonia, acid halogens, and a small amount of aromatic hydrocarbons (NRC 1999). These are controlled by downstream air pollution control systems. The thermal reduction batch processor used for treatment of solid substrates can be expected to retain 10% of the introduced organic solids as soot (NRC 1999). The soot constitutes a solid waste stream that must be landfilled.

Capital and operating costs

The capital cost for a semi-mobile operating plant capable of XXX lb of throughput per year is XXX, as estimated by SAIC. At this throughput, SAIC also estimates the operating cost to be XXXM per year.

Given the capital and operating cost estimates, the present cost for 10 years of disposal operations with a GPCR system may be estimated using a discount rate of XXX (OMB 2010). By this estimate, the 10-year present cost of operating a GPCR unit is approximately XXXM.

6 Supercritical Water Oxidation

Process description

Supercritical water oxidation (SCWO) (Figure 9) is a high-temperature and high pressure technology to destroy organic compounds and toxic wastes through oxidation. SCWO oxidizes the mixture in the vessel through a rapid reaction. The primary products from the process are water, carbon dioxide, and salts. The process combines wastes with water, air, and fuel into a vessel operating at 3200 psi and 650 °C. Quench water is supplied to cool the oxidized effluent to below its critical temperature. After decreasing the effluent stream pressure, the effluent is sent to a gas liquid separator. Because no hazardous pollutants are formed, the gas stream is vented to the atmosphere and the liquids and solids are recovered and disposed. Energetics require pretreatment to neutralize the chemical agent before SCWO can occur. Munitions are disassembled to separate the chemical agent from the energetics, which is mixed separately with caustic solution or water. Supercritical water oxidation is suited for pumpable organics including slurry mixtures. SCWO is processed in an enclosed treatment facility and has approximately XXX destruction efficiency. If enough quench water is supplied, the salts formed can pass through to the separator.

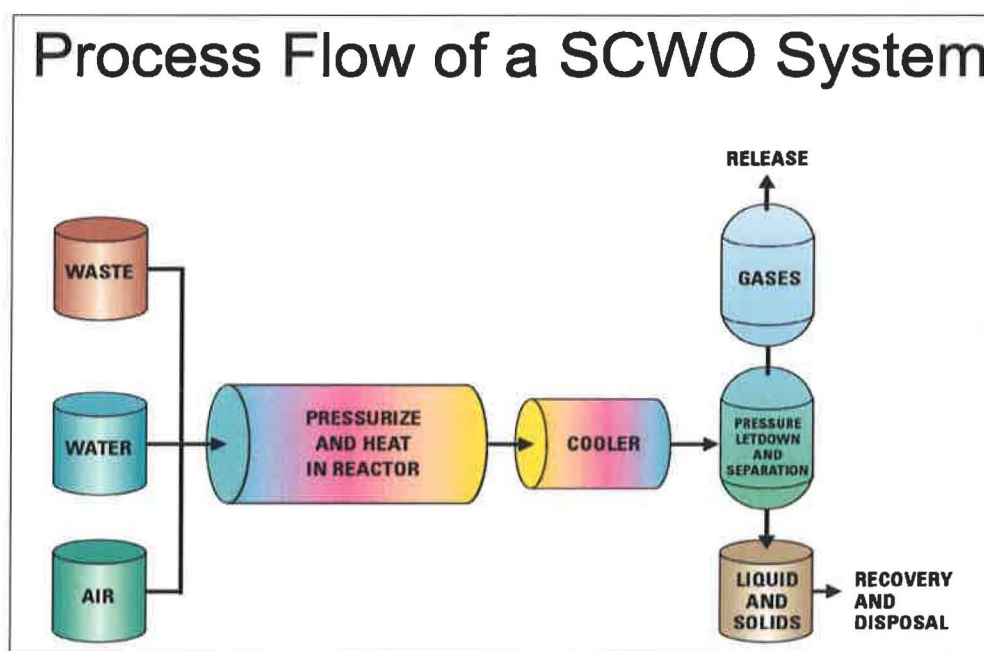


Figure 9 Supercritical water oxidation (SCWO) system.

The General Atomics system can operate at up to XXX gpm corresponding to a yearly capacity of XXX lb of explosive waste when treated as XXX slurry. A XXX by weight slurry mix is standard for incinerator operation, though the capacity of the system may be significantly increased by feeding higher solids content slurries. General Atomics is testing the safety of higher solids content slurries. SCWO is a suitable decomposition technology for any material that can be handled as a water slurry. This includes all pile and cage wastes, ANsol, and wood or plastic pile wastes that have been wet ground to slurry conditions.

Current applications

SCWO technology has been installed in a variety of applications. General Atomics has been developing SCWO systems since the early 1990s, and has systems at Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP), Kentucky, and Tooele Army Depot (TEAD), Utah (Wong 2011). Organo Corporation has installed a SCWO system for the treatment of halogenated waste in Japan. The largest commercial SCWO application is a catalyst treatment and precious metal recovery application by Chematur Engineering AB (Sweden).

Safety profile/engineering controls

SCWO treatment requires a combination of high temperature and high pressure. A current unknown is the explosives feed system. As with incineration, traditional SCWO feed for explosives is water slurry, though efforts are under way to test the safety of processing undiluted energetic materials (Department of the Air Force 2011).

Waste streams

SCWO produces a low amount of NO_x and SO_x and no dioxins or furans. This allows the gases produced to be vented to the atmosphere. The liquids and solids created are recovered from the gas liquid separator and are ready for disposal. Military applications at TEAD and BGCAPP are currently undergoing regulatory permitting.

Capital and operating costs

A SCWO system with an operational capacity of 3 gpm has a capital cost of approximately XXX million. The estimated annual operating costs are listed in Table 4. The system requires one operator shift per day. Utility estimates

are based on an average of \$XXX per kW-hr of electricity, and XXX per thousand cubic feet of natural gas. Given the capital and operating cost estimates, the 10-year present cost of disposal operations with a SCWO system may be estimated using a discount rate of XXX(OMB 2010). By this estimate, the 10-year present cost of operating a SCWO unit is approximately \$XXXM.

Table 4. Estimated annual costs for SCWO system.

Utilities			\$/year
Natural Gas			XXX
Electricity			XXX
Operating Labor Cost (C_{OL})			
Operators per Day	\$/hr	d/yr	\$/yr
X	XXX	XXX	XXX
Miscellaneous Labor (xxx_{oL})			XXX
Yearly Maintenance (XXXC_c) (C_c=XXX)			XXX
Estimated Annual Operating Costs			XXX

7 Summary

The five evaluated technologies are summarized in Table 5. The first and most important consideration in any comparison is the safety profile of the system. Each of these systems is commercially available with acceptable engineering controls for safety, but the GPCR process has not been demonstrated for disposal of bulk explosives. Given the current uncertainty of its safe application for explosives, GPCR is not recommended as an appropriate technology. Of the remaining technologies, alkaline hydrolysis is the least expensive option, but one that has limited applicability to current and future solid waste disposal needs at HSAAP. The static kiln is an excellent option for demilitarization of assembled munitions, though for application at HSAAP the built-in safeguards required for demilitarization are probably responsible for a higher present cost over 10 years compared to other options. Rotary kiln incineration and SWCO technology each have applicability to all present and future wastes at HSAAP with comparable costs. There is uncertainty with an SCWO system in the required size reduction of wastes before treatment. This will probably require a wet grinding step that is not included in this review.

Incineration remains the most certain and cost-effective explosive waste disposal method. The greatest uncertainty with this technology is associated with the ability of operators to secure air quality permits. Recent efforts to install and operate a rotary kiln at Picatinny Arsenal have been met with resistance. The U.S. Environmental Protection Agency considers hazardous waste incineration to be a declining industry (Reitze 2005).

In conclusion, HSAAP maintains a permitted and functional explosive waste disposal system. Possible regulatory changes and alterations to available waste recycling may change the approach that HSAAP must take to its current practices. If that is the case, incineration technologies remain the most certain, safe, and cost-effective method for explosives waste disposal. Given the prospect of regulatory issues, though, incineration is not viable. SCWO technologies are rapidly developing, and are a viable option for possible future installation. The specific properties of the static kiln that make it a good option for assembled munitions disposal lead to extra capital costs. Otherwise, a static kiln is a viable option. Alkaline

hydrolysis and GPCR processes are not applicable to the full range of wastes generated by HSAAP. As HSAAP moves forward, the highest level of confidence for successful replacement of open burning that may be expected is with SCWO technology, followed by static kiln technology.

Table 5. Summary of evaluated technologies.

Technology	Vendor	Applicability	Safety	Maturity	Capital Cost	10-Year Present Cost
Alkaline Hydrolysis	Pfaudler	Bulk explosives only	Chemical hazards, well defined engineering controls	Demonstrated technology	*	*
Static Kiln	UXB Int.	All explosive wastes, size reduction required for pile waste, ANsol unknown	Good with established engineering controls	Commercially available, mature technology	*	*
Incineration	Varied	All wastes	Good with established engineering controls	Commercially available, mature technology	*	*
GPCR	SAIC Inc.	Small articles with surface contamination, applicability not tested for bulk explosives or ANsol	Unknown, not tested for bulk explosives	Mature technology for liquid organic wastes, not demonstrated for bulk explosives	*	*
SCWO	General Atomics	All wastes, grinding and slurry phase injection required for cage and pile waste	Good with established engineering controls	Demonstrated technology with full scale	*	*

*As per the Freedom of Information Act Guide, May 2014, Exemption 4 the Army cannot release "trade secrets and commercial or financial information obtained from a person [that is] privileged or confidential."

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Appendix A: Vendor White Papers

This appendix includes white papers provided by process vendors which contains proprietary information. As per the Freedom of Information Act Guide, May 2004, Exemption 4, the Army cannot release "trade secrets and commercial or financial information obtained from a person [that is] privileged or confidential." This information can be directly solicited from the vendors.

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13. SUPPLEMENTARY NOTES					
14. ABSTRACT Production of potentially dangerous explosive or explosives-contaminated waste materials is inherently linked to the production of explosives. These waste materials are most safely disposed of by an onsite decomposition method, and current best practice is an open burning method. As the Army industrial base modernizes, though, the environmental effects of open burn processes have come under greater scrutiny. Efforts to identify and demonstrate alternative explosive waste disposal technologies at Army ammunition plants have been underway for at least 40 years. This report delineates the current state of practice for alternative disposal options with reference to possible application at Holston Army Ammunition Plant (HSAAP). The objective is to compare commercially available disposal technologies in the event that open burning becomes environmentally or financially unfeasible for application at HSAAP. Incineration technologies remain the most certain, safe, and cost-effective method for explosives waste disposal. Given the prospect of regulatory issues, though, incineration is not viable. Supercritical water oxidation (SCWO) technologies are rapidly developing, and are a viable option for possible future installation. The specific properties of the static kiln that make it a good option for assembled munitions disposal lead to extra capital costs. Otherwise, a static kiln is a viable option. Alkaline hydrolysis and gas phase chemical reduction (GPCR) processes are not applicable to the full range of wastes generated by HSAAP. As HSAAP moves forward, the highest level of confidence for successful replacement of open burning that may be expected is with SCWO technology, followed by static kiln technology.					
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