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Alternatives for the Disposal of Energetic Waste at the Clean Harbor's Colfax LLC Open Burn Open Detonation Facility, Colfax, Louisiana

Final Review Report
SWRI 01-78355
SwRI® Project 22414

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1. INTRODUCTION

1.1 Objective

The objective of this review was to assess alternatives to open burning and open detonation (OBOD) of energetic materials at the Clean Harbors Colfax LLC (CHC) facility in Grant Parish, Louisiana. Clean Harbors Environmental Services, Inc., the owner and operator of the thermal treatment facility, requested this independent technical assessment study from Southwest Research Institute (SwRI) in response to local opposition to the OBOD of the 561,700 lbs net explosive weight (NEW) of waste energetic materials the facility is permitted to accept for thermal treatment annually. This report summarizes the current operations at the CHC, facility and analyzes alternative technologies with the potential to replace the current OBOD treatment process.

1.2 Background

The disposal of waste energetics is an international challenge with many nations actively involved in disposal of waste or off-specification explosives, propellants, obsolete ammunition, unexploded munitions from past conflicts, waste explosives from mining and oil fracking operations, fireworks, and other pyrophoric material. The CHC, explosive waste treatment facility is one of only three permitted commercial facilities that accept and treat explosive hazardous waste in the United States. There are a number of treatment facilities owned and operated by the Department of Defense (DoD) for disposal of waste military explosives, ammunition, and propellants. Recently, the Louisiana National Guard was required to contract for a new thermal treatment system to dispose of 15 million pounds of M-6 propellant and 3 million pounds of other explosives at Camp Minden, Louisiana. A contained burn furnace and associated pollution abatement system was selected from a wide spectrum of proposed technologies by the Camp Minden Dialog Group and approved by the Environmental Protection Agency (EPA) to treat this large volume of a single propellant and clean burning igniters . The system was installed and the contractor, Explosive Service International Inc. (ESI), has destroyed over 11 million pounds of the M-6 and anticipates completion by May 2017.

Nationally, the Colfax facility is the only commercial facility permitted to use OBOD for destruction of energetic materials. There is pressure from the local community and environmental advocates due to general resistance to OBOD of hazardous waste, concerns that the public is being exposed to toxic and hazardous pollutants (e.g. lead), and objections to the visible black smoke from the diesel used as an ignition source. In Louisiana, the public interest in energetic waste destruction was heightened by previous accidents and the subsequent public participation in the selection of a thermal treatment system for the destruction of over 15 million pounds of propellant at Camp Minden in Northern Louisiana. This occurred at the same time the Colfax facility requested a permit modification to increase their allowed NEW per year from 561,700 lbs NEW/year to 2,055,000 lbs NEW per year to potentially treat the propellant at Camp Minden. The Colfax facility subsequently withdrew its request. This opposition from local environmental advocacy organizations also generated a House Concurrent Resolution in the Louisiana State Legislature (HCR 118) which directed the Louisiana Department of Environmental Quality to perform environmental sampling of the soil, groundwater, and air on the CHC facility and to form a dialog committee with the local community.

In response to the public reaction to its request for a permit modification and heightened visibility of its energetic thermal treatment operations at Colfax, Clean Harbors Environmental Services, Inc., requested that Southwest Research Institute (SwRI) conduct an independent investigation of alternatives to OBOD for disposal of energetic wastes at the CHC facility. SwRI is one of the largest non-profit research foundations in the United States. The ten operating divisions perform contract research and development, test and evaluation in every area of science and engineering from deep sea to deep space. The Chemistry and Chemical Engineering Division of SwRI has over 32 years of experience supporting hazardous munitions waste disposal. Much of that work centered on technology validation in support of chemical agent munitions destruction, decontamination, and disposal. The authors of this report have over 50 years of experience in explosive, propellants and pyrotechnics safety, and disposal technologies.

1.3 Assessment Approach

To assess the applicability of potential technologies as alternatives to the current permitted OBOD operation, SwRI reviewed the technical literature on energetics disposal, previous technology reviews of alternatives to OBOD such as at Camp Minden, and vendor presentations and literature. The challenge of assessing technology for an energetics thermal treatment facility is the variety of energetic materials that must be safely received, handled, and treated in a manner protective of the workers, public, and the environment. This is a very different energetic waste stream than the large volume of homogeneous propellant being treated at Camp Minden. The Colfax facility was visited, the operation observed, and the waste stream records reviewed to determine the quantities and types of energetics received and treated over the last 3 years. As will be discussed later, the Colfax facility received over 210 different types of energetic items, many of which must be uniquely disassembled and reduced in size. Finally, a request for information was sent to the vendors of the various energetic destruction technologies requesting information on characteristics of their systems, ability to accommodate the Colfax facility waste stream, and a description of their industrial experience and safety record.

2. DESCRIPTION OF THE CLEAN HARBORS COLFAX FACILITY

The CHC facility is located on 642 acres of isolated rural land off Highway 471, approximately three miles from Colfax, Louisiana. The majority of the facility is wooded rolling hills and the actual permitted thermal treatment unit and associated storage and preparation activities are limited to approximately 43 acres in the center, approximately 0.5 miles from the outer boundary fence (Figure 1). The administrative trailer and associated maintenance building are outside of the treatment facility. A pond is located near the front of the facility.

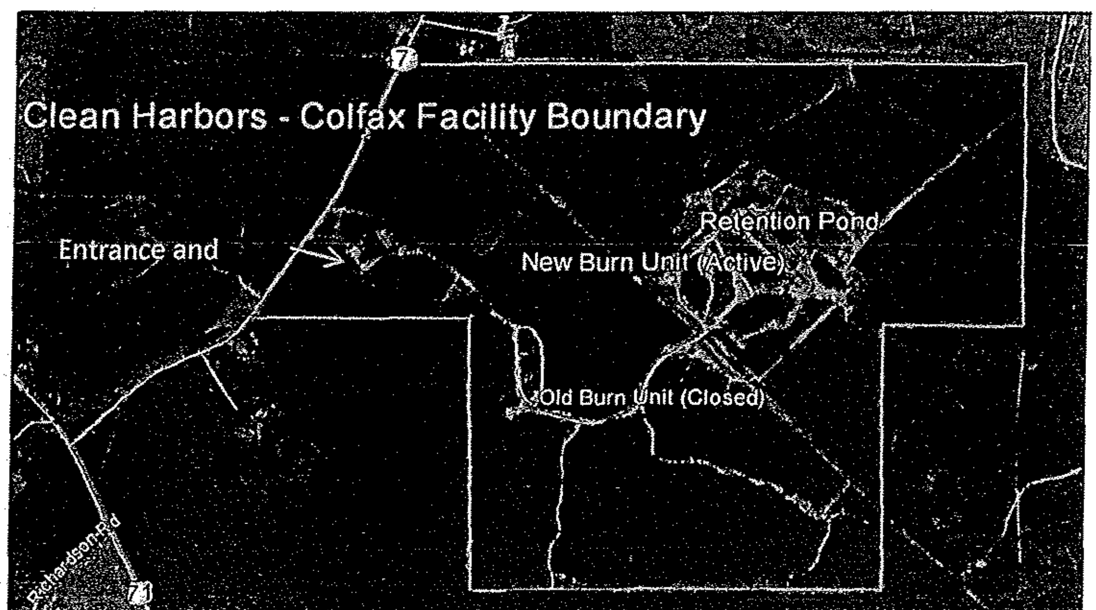

Figure 1. CHC Facility[1]

[1] Louisiana Department of Environmental Quality, (2017) HCR 118 Air Sampling and Analysis Plan Clean Harbors Colfax LLC, Colfax Louisiana, Grant Parish, 1120-00010-04, AI No. 32096

2.1 Utilities

Water is procured from the city and is not up to industrial supply requirements for fire suppression. Other utilities such as gas and electricity are also provided by local utilities, but the capacity is unknown.

2.2 Security

The facility is located in a rural area with limited neighbors. A single fence surrounds the facility and another is around the operational area. There are no guards, but there is camera surveillance.

2.3 Storage Magazines

The Colfax facility is permitted for ten storage magazines, three of which are permitted for liquid explosive and reactive wastes. Each has a capacity of 11,968 gallons or 5,000 pounds net explosive weight (NEW) or 59.3 yd^3 of waste. There is a separate storage area for poisonous and/or reactive compressed gas cylinders which contains multiple cylinders of various sizes. The covered staging area for the liquid storage magazines (8–10) has a maximum truckload capacity of eighty 55-gallon drums of liquid waste. The storage magazines are required to be at least 15 meters from the facility lines. Class 1 magazines must confirm to U.S. Bureau of Alcohol Tobacco and Firearms (ATF), Department of Treasury Regulations.

2.4 Preparation Building

The 1,400-square foot Preparation Building is designed for disassembly of devices prior to treatment and is located approximately 200 yards from the control room. The preparation includes water cooled sawing and drilling devices to provide access to the explosive and reactive material and to properly size prior to thermal treatment. Some preparation is also performed on the burn pads. Multiple saws are available to handle different size devices. No one is allowed in the Preparation Building during a sawing or drilling operation, and the saws are operated remotely from a separate control room. All the operations are viewed using cameras. The capacity of the Preparation Building is 410 pounds/hour and no overnight storage is allowed in this area. All the waste prepared must be treated that day or returned to one of the permitted areas for overnight storage.

2.5 Container Storage Area

There is an 18-ft x 60-ft container storage area at the rear of the Preparation Building that is permitted for up to 2,500 gallons or 60 yd^3 of hazardous waste. This waste can be stored up to one year.

2.6 Open Burn Open Detonation (OBOD) Thermal Treatment Unit

Thermal treatment of the explosive and reactive wastes takes place on a 700-ft x 130-ft x 6-inch concrete burn slab. The burn slab is located ~1100 ft from the nearest fence line and a little over a mile from the nearest neighbor. There are twenty separate 16-ft x 16-ft x 1.5-ft burn pads on top of the burn slab. Each burn pad supports a burn pan which is permitted to treat a total of 410 lbs/hour. Eighteen of the pans are for characteristic waste, and two are used for listed waste. Trays are preloaded and then brought to the burn area. Configuration of the explosive material on the burn pans is more an art than a prescribed procedure and is based on the ignition properties of the material and experience of the operator. The objective is to contain and hold heat and avoid materials "hopping" out of the pans onto the burn pad. The maximum throughput is limited to 410 lbs/hour for the thermal treatment unit. Thermal treatment is facilitated by the use of a low volatility Number 2 diesel. The facility is permitted to operate seven days per week during daylight hours (8 am to 5 pm) but only operate six days/week. Pressurized cylinders are breached with a linear shape charge in a pan.

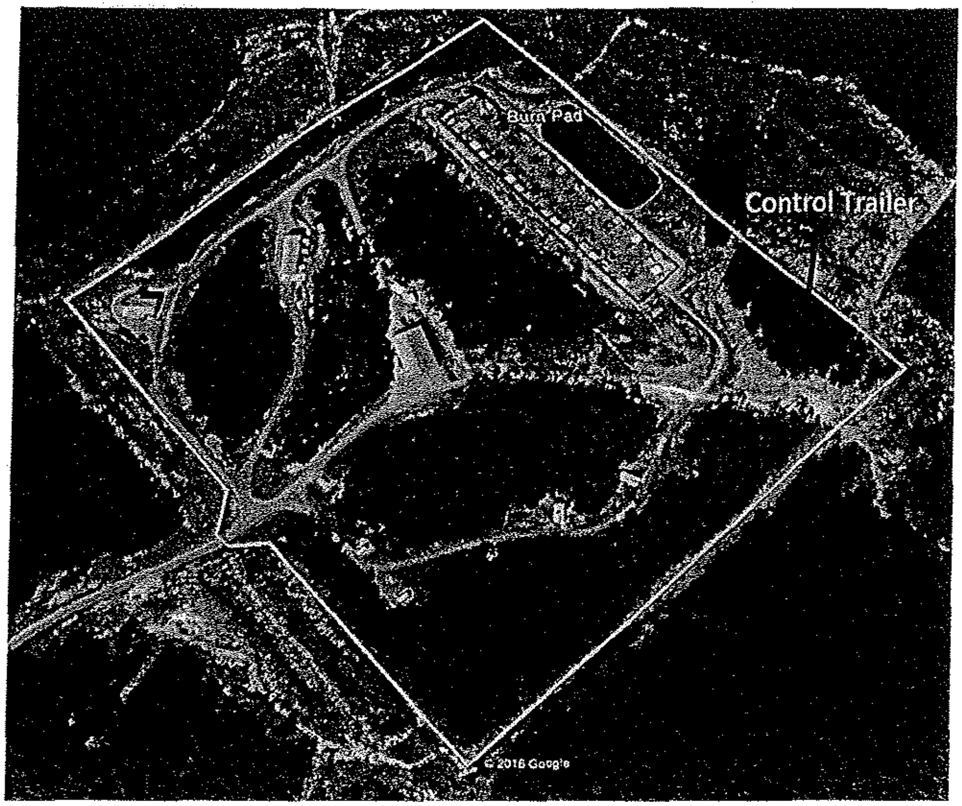

Figure 2. Thermal Treatment Unit 1

As shown in Figure 2, the thermal treatment is operated remotely from a control trailer located 480 ft up the hill from the thermal treatment unit. In discussing the operation of the thermal treatment unit with the General Manager, Jerry McPherson, up to ten pans can be burned at one time and up to nine burns per day, except when the wind speed exceeds 10 mph or there are electrical storms within a three-mile radius of the facility. The NEW limit is 410 lbs/hr. Work day is from 8 am to 5 pm only when there is no rain or lightning. All fires must be out by 5 pm. Water wetted materials present the greatest technical challenge to burn completely because of the requirement to completely burn the waste. Use of isopropyl alcohol as an alternative to diesel would help alleviate this challenge and would significantly reduce the visible black smoke that draws attention from the public. The pans are allowed to cool down for four hours before removal of the residue. Each burn pan is limited to one waste profile. Operations (physical preparation of waste, transport to the thermal treatment unit, treatment and inspection after the cool down) are limited to daylight hours between 8 am and 5 pm.

2.7 Environmental Monitoring

Quarterly environmental monitoring is conducted in accordance with the approved *Tier 1 Detection Monitoring Work Plan* (approved 1 December 2011). The approved plan requires quarterly media (soil, surface water and sediment) sampling and reporting. The most recent quarterly report dated June 15, 2016 contains a statistical evaluation of all seventeen quarterly sampling events.[2] A map of the thermal treatment unit and the sampling locations are shown in Figure 3. No air monitoring is currently conducted; however, discussions are ongoing with the Louisiana Department of Environmental Quality (LDEQ) for a more comprehensive sampling and monitoring program in response to recent local concerns.

[2] EcoScience Resource Group, Clean Harbors Colfax, LLC First Quarter 2016 Tier1 Detection Monitoring Report, June 15, 2016

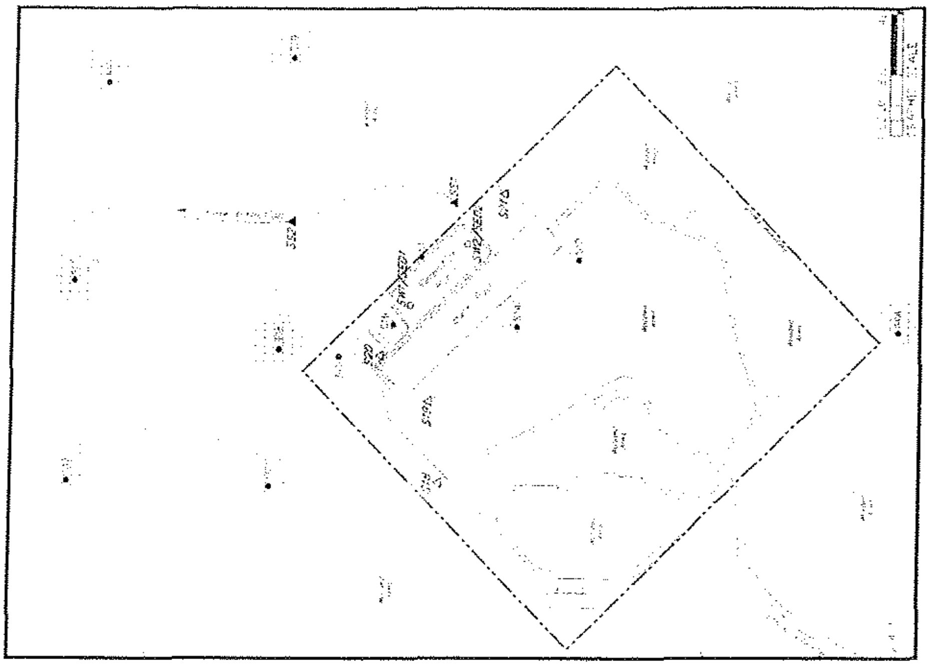

Figure 3. Environmental Monitoring Locations 2

2.8 House Concurrent Resolution 118 Environmental Monitoring

As a result of the Louisiana Legislature House Concurrent Resolution No.118, the Louisiana Department of Environmental Quality (LDEQ) developed and implemented a sampling plan to test the soil, groundwater and air during normal OBOD operations at the CHC facility.[3]

2.8.1 Soil Sampling

The sampling took place 10–19 October 2016, during which samples were collected from the retention pond, outfall 001 sediment and water at the facility perimeter (Figure 4).

[3] Louisiana Department of Environmental Quality (2017) House Concurrent Resolution 118 Representative Reynolds and Senator Walsworth, Clean Harbors Colfax LLC, Colfax, Louisiana, Grant Parish, AI NO. 32096

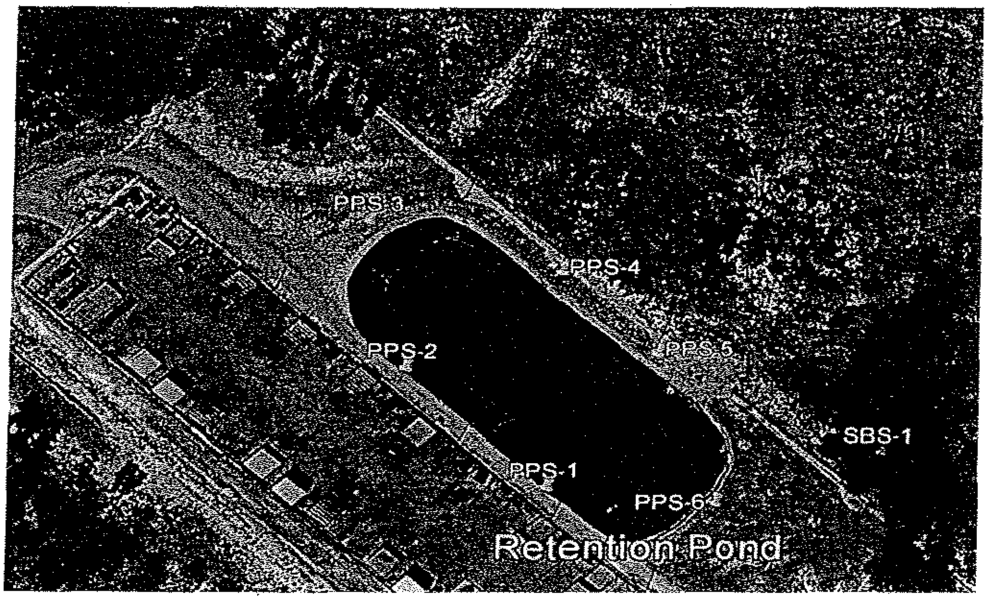

Figure 4. HCR 118 Soil and Streambed Sampling Locations [4]

Soil in the vicinity of the thermal treatment pad was found to contain low concentrations of volatile organic compounds (VOCs), dioxins and furans (PCDD/PCDF), metals, perchlorate and nitrate, all below the Risk Evaluating/Corrective Action Program (RECAP) regulatory standards. These are based on EPA screening standards (SS) for maximum exposure parameters and toxicity values that do not present unacceptable risk to human health or the environment. At the facility perimeter, only one VOC, metals and dioxin/furans were found again at concentrations that were below the SS.

The only soil sample that exceeded the SS was located in the outfall of the retention pond that might be indicative of potential downstream contamination by surface water transport and deposition. This sample contained lead (347 mg/kg) above the SS for soil (100 mg/kg) that is protective of groundwater (SS_{SSGW}). As a result of this finding, the LQEQ is requiring the Colfax facility to perform a synthetic precipitation leach procedure (SPLP) to determine if lead may leach into the groundwater at unacceptable levels. No explosives or semivolatile organic compounds (SVOC) were detected in soil of streambed sediment.

2.8.2 Groundwater Sampling

Groundwater samples were taken from four temporary monitoring wells in the vicinity of the retention pond and compared to SS protective of groundwater used for drinking water (Figure 5). The samples were taken in the uppermost aquifers sand layers between 14 and 40 ft below ground. The analysis of the samples revealed three VOCs, one SVOC, dioxin/furans, nitrogenous compounds, perchlorate and explosive compounds. The only compounds detected above the SS were bis (2-ethylhexyl) phthalate (0.015 mg/L, SS = 0.006 mg/L) at one well and the explosive RDX (0.001 mg/L, SS = 0.0006 mg/L) and perchlorate (0.046 mg/L, SS = 0.0026 mg/L) at another well.

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[4] Louisiana Department of Environmental Quality, (2017) HCR 118 Soil Sampling Summary Report Clean Harbors Colfax LLC, Colfax Louisiana, Grant Parish, 1120-00010-04, AI No. 32096

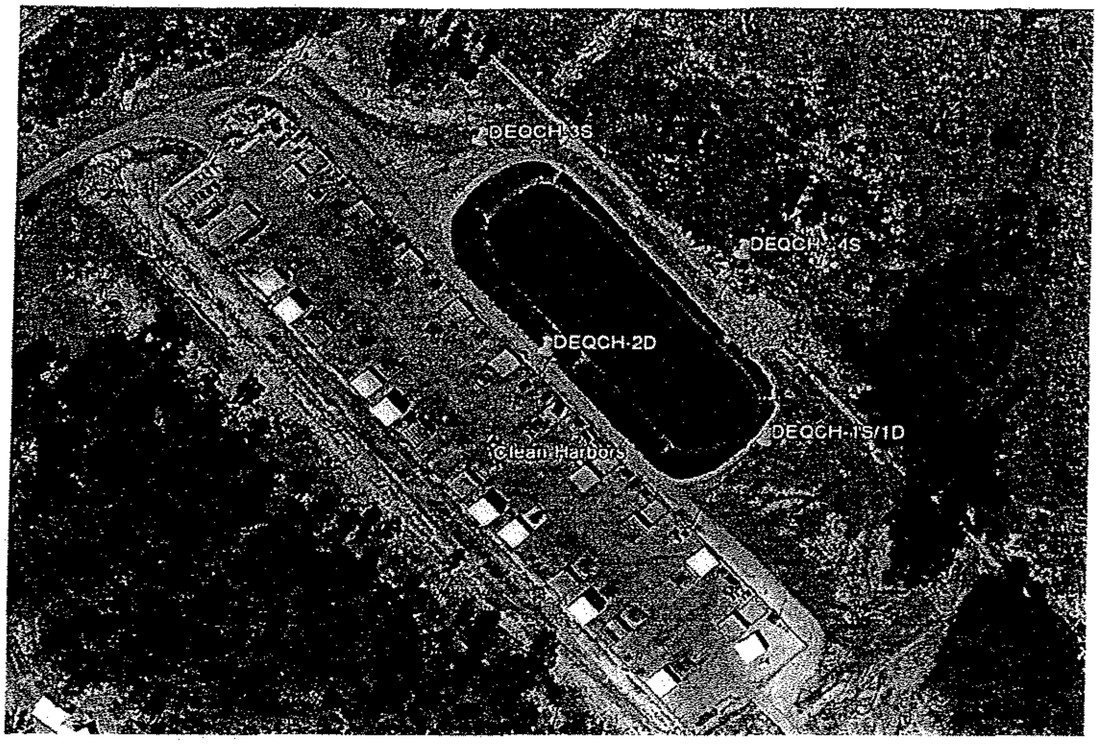


Figure 5. HCR 118 Groundwater Sampling Locations [5]

Attempts to collect groundwater samples at the perimeter were unsuccessful due to the inability to find sufficient water to sample.

As a result of the detection of these compounds above the SS, the LDEQ is requiring the Colfax facility to delineate the horizontal and vertical extent of groundwater contamination. This data will be used by the LDEQ to evaluate the potential for off-site migration and the need for any corrective action.

2.8.3 Air Monitoring

Air samples were collected at the locations shown in Figure 6 upwind (background), at the facility fence line, and in the nearby residential community to evaluate the air quality during OBOD operations. The amounts burned during each sampling event are shown in Figure 7.[6]

[5] Louisiana Department of Environmental Quality, (2017) HCR 118 Groundwater Sampling Summary Report Clean Harbors Colfax LLC, Colfax Louisiana, Grant Parish, 1120-00010-04, AI No. 32096

[6] Louisiana Department of Environmental Quality, (2017) HCR 118 Air Sampling Summary Report Clean Harbors Colfax LLC, Colfax Louisiana, Grant Parish, 1120-00010-04, AI No. 32096

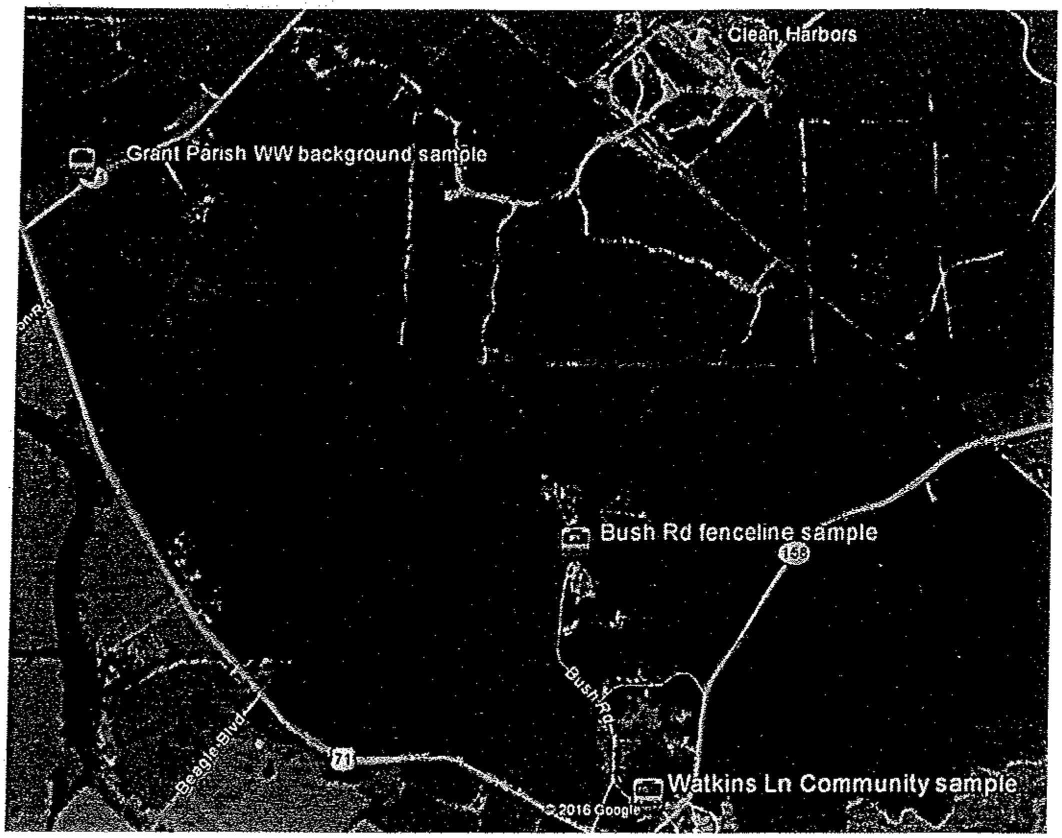
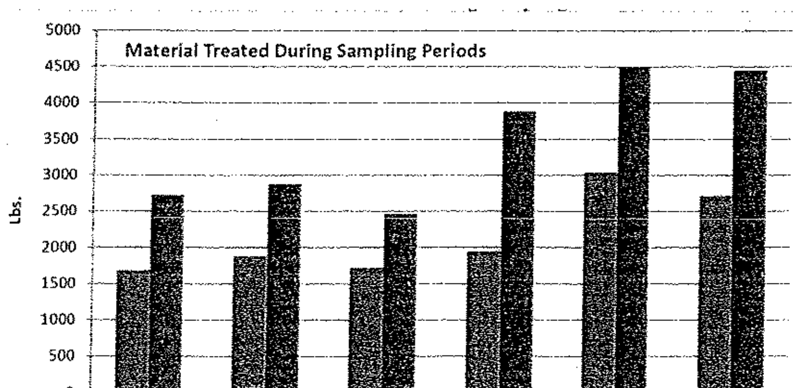


Figure 6. HCR 118 Air Sampling Locations 6



* Net Explosive Weight	11/3/2016 Community (8 Burns)	11/4/2016 Community 24-Hour (7 Burns)	11/5/2016 Community (5 Burns)	11/9/16 Perimeter (7 Burns)	11/10/16 Perimeter 24-Hour (8 Burns)	11/11/16 Perimeter (8 Burns)
N.E.W.*	1683	1883	1723	1951	3043	2721
Gross	2730	2883	2469	3886	4496	4460

Figure 7. Energetic Material Burned during the LDEQ Air Monitoring Events 6

The air testing results indicated that particulates, carbon dioxide, dioxin/furans, metals, VOCs and SVOCs were detected in the background, at the fence line, and in the community; however, all concentrations were below the National Ambient Air Quality Standards (NAAQS) and the Louisiana Toxic Air Pollutant Ambient Air Standards (LAAS). For many analytes, the concentrations in the background or community were higher than at the facility fence line due to the low levels and the normal activities of living in the residential areas. No explosive compounds or perchlorate were detected at any of the monitoring stations.

In the past, the public has raised concerns over emissions of toxic metals and dioxin/furans during the OBOD operations. There was no lead or other toxic metals detected above background except magnesium. As shown Figure 8, Dioxin/Furans at the fence line were also similar to the background and those found in the community and well below the Louisiana Toxic Air Pollutant Ambient Air Standards (LAAS) of 3000 pg/m^3. Figure 9 shows the Dioxin/Furan in toxicity equivalencies where 2,3,7,8 TCDD (the most toxic of the isomers) is assigned a value of 1. The Colfax facility has committed to continue fence line air monitoring in the future. No lead was detected in any of the samples.

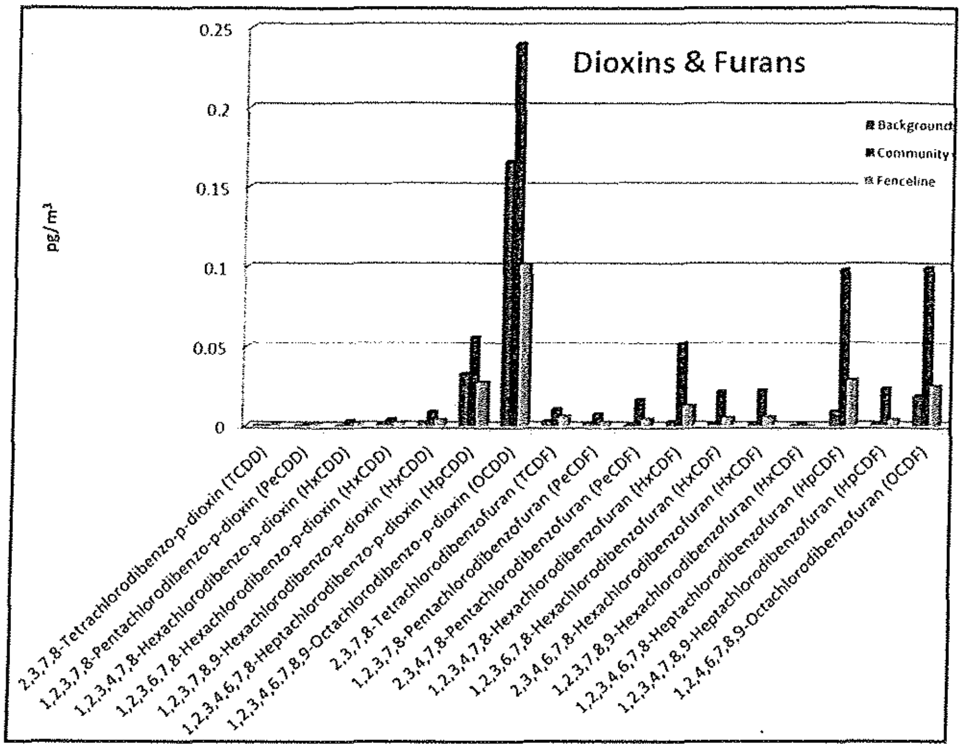


Figure 8. HCR 118 Dioxin/Furan Monitoring Results 6

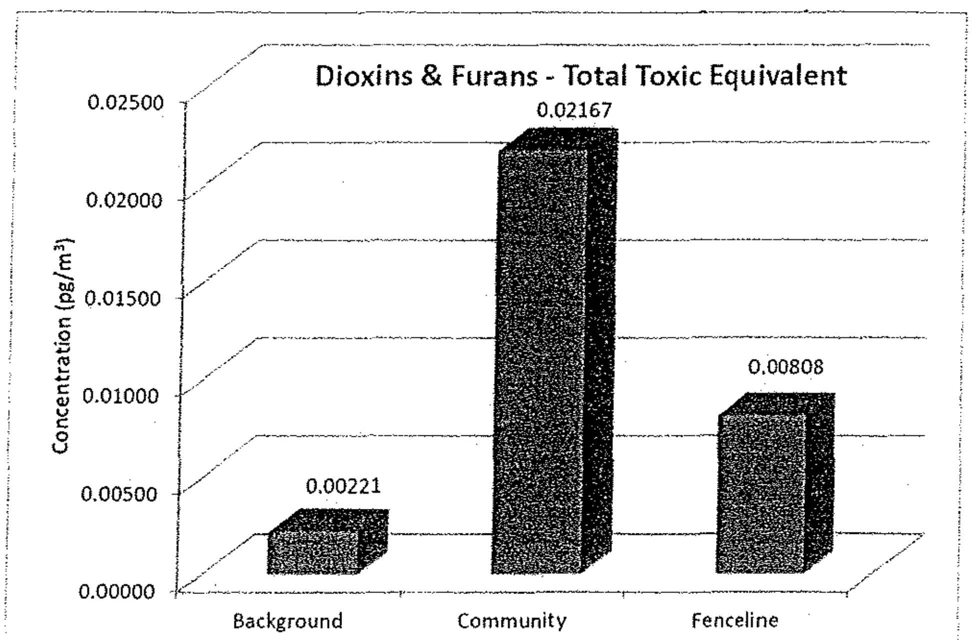


Figure 9. HCR 118 Dioxin/Furan Toxicity Equivalency [6]

3. WASTE STREAM

3.1 Waste Types

The facility is permitted to treat hazardous waste by open burning and detonation of explosives, including waste which has the potential to detonate and bulk propellants which cannot be safely disposed of through other modes of treatment. The predominant waste stream is made up of EPA Hazardous Waste Number D003, solid waste with a characteristic of reactivity. (All incoming wastes include D003). The characteristic of reactivity is described below in Table 1. All transport of waste to the site is by long haul trucks with no rail head available.

Table 1. Characteristic of Reactivity [7]

A solid waste exhibits the characteristic of reactivity if a representative sample of the waste has *any* of the following properties:

(1) It is normally unstable and readily undergoes violent change without detonating.

(2) It reacts violently with water.

(3) It forms potentially explosive mixtures with water.

(4) When mixed with water, it generates toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.

(5) It is a cyanide or sulfide bearing waste which, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.

(6) It is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

(7) It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

(8) It is a forbidden explosive as defined in 49 CFR 173.54, or is a Division 1.1, 1.2 or 1.3 explosive as defined in 49 CFR 173.50 and 173.53.

Other waste designations allowed under the permit include D001 (ignitability), D002 (corrosivity), and toxicity due to specific toxic constituents as determined using the Toxicity Characteristic Leach Procedure, K044, K045 and K046- waste from specific industrial sources (wastewater treatment sludges and carbon from explosive manufacturing and lead-based initiating compounds, P009, P048, P065, P081, P105 and P112 explosive chemicals such as ammonium picrate, 2,4 dinitro phenol, fulmic acid, sodium azide, and trinitromethane.

3.2 Waste Stream

The facility is permitted to thermally treat 561,700 lbs (net explosive weight) per year. The complexity of the waste stream facility must safely receive, handle and treated is illustrated by the 39 typical waste material families listed in the air permit and the hundreds of categories of energetics received in the last three years.[8] Table 3 lists 95% of the explosive and reactive wastes treated over the last three years as a function of their United Nations (UN) or North American (NA) numbers that identify hazardous articles and materials in the context of international transport. The other categories not shown in Table 3 were less than 0.2% of the total weight each. As shown in Table 3, the facility burned 387,875 lbs, 410,932 lbs, and 284,679 lbs in 2014, 2015 and 2016, respectively. While the facility processed over 210 categories of materials, almost 50% of the total weight processed comes from just three categories: Substances Explosive N.O.S. 1.1D, 1.3C, and solid propellant 1.3C. Over 80% of the material burned was in only 16 categories.

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[7] 40 CFR 261 Identification and Listing of Hazardous Waste

[8] Louisiana Department of Environmental Quality, (2014) Clean Harbors Colfax, LLC Air Permit No. 1120-00010-04

Other categories each had less than 1% of the total over three years. In 2016, the most recent reporting year, slightly over the 53% of material disposed of was in four categories: Substances Explosive N.O.S. 1.1D, 1.3C, 1.4C, and solid propellant 1.3C indicating the waste stream remains reasonably consistent, however, this last year the total quantity was almost 50% less than the two previous years.

Of the wastes treated, 42.9% was class 1.1, 32.5% was class 1.3 and 15.1% was class 1.4. Of the Class 1.1, almost all was 1.1D. For the reader unfamiliar with the explosive classification system used in the descriptors, the common classification codes and compatibility groups are given in Tables 4 and 5.

Table 2. Most Prevalent Materials Burned (Lbs) as a Function of UN Number [9]

UNNA Nos.	Type	DOT Class	DOT Code	2014	2015	2016	3 YTD	Percentage	Cum. Percent
UN0475	Substances Explosive , N.O.S.	1.1	D	81,813	148,037	36,751	266,601	25.99%	25.99%
UN0499	Propellant, solid	1.3	C	55,874	48,306	42,750	146,930	14.32%	40.31%
UN0477	Substances Explosive , N.O.S.	1.3	C	35,818	41,693	13,920	91,431	8.91%	49.23%
UN0479	Substances Explosive , N.O.S.	1.4	C	25,052	29,557	22,684	77,293	7.54%	56.76%
UN0484	HMX, desensitized	1.1	D	35,194	5,522	8,827	49,543	4.83%	61.59%
UN0478	Substances Explosive , N.O.S.	1.3	G	12,458	14,919	8,771	36,148	3.52%	65.12%
UN0161	Smokeless powder	1.3	C	17,733	1,961	13,299	32,993	3.22%	68.33%
UN0333	Fireworks	1.1	G	23,348	5,848		29,196	2.85%	71.18%
UN0351	Articles explosive	1.4	C	1,737	10,465	11,370	23,572	2.30%	73.48%
UN0042	Booster w/o detonators	1.1	D	5,553	4,782	6,461	16,796	1.64%	75.12%
UN0186	Rocket motors	1.3	C	605	15,239	415	16,259	1.59%	76.70%
UN0282	Nitroguanidine or picrite < 20% by wt water	1.1	D	15,475	40		15,515	1.51%	78.21%
UN0440	Charges, shaped w/o detonators	1.4	D	4,782	4,803	2,417	12,002	1.17%	79.38%
UN0093	Flares, aerial	1.3	G	134	7,602	3,681	11,417	1.11%	80.50%
UN0065	Cord, detonating, flexible	1.1	D	10,504	237	41	10,782	1.05%	81.55%
UN0012	Ammunition Sporting	1.4	S	7,998	1,718	1,063	10,779	1.05%	82.60%
UN0027	Black powder	1.1	D	3,299	1,487	3,703	8,489	0.83%	83.43%
UN0336	Fireworks	1.4	G	437	4,061	3,939	8,437	0.82%	84.25%
UN0482	Substances, Explosive very insensitive	1.5	D		7,876		7,876	0.77%	85.02%
UN0485	Substances Explosive , N.O.S.	1.4	G	2,433	2,573	2,681	7,687	0.75%	85.77%
UN0072	Cyclonite	1.1	D	4,079	1,603	636	6,318	0.62%	86.38%
UN0055	Cartridge case, Empty primer	1.4	S	3,144	2,903	96	6,143	0.60%	86.98%
UN0242	Bag Charges	1.3	C	1,425	4,291	68	5,784	0.56%	87.54%
UN0118	Hexolite (dry or wet < 15% water)	1.1	D	4,789	841	136	5,766	0.56%	88.11%
UN0483	Hexagon	1.1	D	4,119	1,095	547	5,761	0.56%	88.67%
UN0016	Grenades, smoke	1.3	G	526	5,077	40	5,643	0.55%	89.22%
UN0463	Articles Explosive N.O.S.	1.1	D	296	1,400	3,768	5,464	0.53%	89.75%
UN0473	Substances Explosive , N.O.S.	1.1	A	2,433	1,755	1,025	5,213	0.51%	90.26%
UN0390	TNT mixed with aluminum	1.1	D	5,004			5,004	0.49%	90.75%
UN0335	Fireworks	1.3	G	2,408	1,694	175	4,277	0.42%	91.16%
UN0197	Signals. Smoke	1.4	G	395	3,449	139	3,983	0.39%	91.55%
UN0391	Cyclonite	1.1	D	1,325	2,292		3,617	0.35%	91.90%
UN0414	Charges, propelling for cannon	1.2	C			3,123	3,123	0.30%	92.21%
UN0323	Power Device, Explosive	1.4	S	2,081	602	87	2,770	0.27%	92.48%
UN3268	Safety Devioce electricaly initiated	9		60	841	1,701	2,602	0.25%	92.73%
UN3491	Organomettalic, water reactive	4.3		196	1,510	879	2,585	0.25%	92.99%
UN3375	Ammunium nitrate emulsion	5.1			706	1,856	2,562	0.25%	93.23%
UN0010	Ammunition incindiary, liquid or gel	1.3	G	1,306	1,168		2,474	0.24%	93.48%
UN0480	Substances Explosive , N.O.S.	1.4	D	1,350	919	125	2,394	0.23%	93.71%
UN3343	Nitroglycerin mixture, desensitiized < 30%	3			1,838	465	2,303	0.22%	93.93%
UN3380	Desensitized Explosive, Solid N.O.S.	4.1		532	70	1,620	2,222	0.22%	94.15%
UN1325	Flammable solids, organic N.O.S.	4.1		1,180	934	94	2,208	0.22%	94.37%
UN0150	PETN with > 15% phlegmatizer	1.1	D	1,971	180	15	2,166	0.21%	94.58%
UN1442	Ammonium perchlorate	5.1		210	1,344	571	2,125	0.21%	94.78%
UN0059	Shaped charges	1.1	D	131	1,367	486	1,984	0.19%	94.98%
UN0006	Ammunition fixed	1.1	E	426	548	927	1,901	0.19%	95.16%
Total				397,343	412,380	216,031	1,025,754	100.00%	

[9] Clean Harbors (2016) UNNA Annual Burn Quantity, Colfax Facility, LA

Table 3. DOT Hazard Class I Divisions [10]

Hazard Division	Hazard
1.1	Mass explosion
1.2	Non-mass explosion
1.3	Mass fire, minor blast or fragment
1.4	Moderate fire, no blast or fragment
1.5	Explosive substance, very insensitive with mass explosion hazard
1.6	Explosive article, extreme insensitive

Table 4. DOT Classification Codes 10

Description of Substance or Article to be Classified	Compatibility Group	Classification Code
Primary explosive substance	A	1.1A
Article containing a primary explosive substance and not containing two or more effective protective features. Some articles, such as detonators for blasting, detonator assemblies for blasting and primers, cap-type, are included, even though they do not contain primary explosives.	B	1.1B 1.2B 1.4B
Propellant explosive substance or other deflagrating explosive substance or article containing such explosive substance	C	1.1C 1.2C 1.3C 1.4C
Secondary detonating explosive substance or black powder or article containing a secondary detonating explosive substance, in each case without means of initiation and without a propelling charge, or article containing a primary explosive substance and containing two or more effective protective features	D	1.1D 1.2D 1.4D 1.5D
Article containing a secondary detonating explosive substance, without means of initiation, with a propelling charge (other than one containing flammable liquid or gel or hypergolic liquid)	E	1.1E 1.2E 1.4E
Article containing a secondary detonating explosive substance with its means of initiation, with a propelling charge (other than one containing flammable liquid or gel or hypergolic liquid) or without a propelling charge	F	1.2F 1.2F 1.3F 1.4F
Pyrotechnic substance or article containing a pyrotechnic substance, or article containing both an explosive substance and an illuminating, incendiary, tear-producing or smoke-producing substance (other than a water-activated article or one containing white phosphorus, phosphide or flammable liquid or gel or hypergolic liquid)	G	1.1G 1.2G 1.3G 1.4G
Article containing both an explosive substance and white phosphorus	H	1.2H 1.3H
Article containing both an explosive substance and flammable liquid or gel	J	1.1J 1.2J 1.3J
Article containing both an explosive substance and a toxic chemical agent	K	1.2K 1.3K
Explosive substance or article containing an explosive substance and presenting a special risk (e.g., due to water-activation or presence of hybergolic liquids, phosphides or pyrophoric substances) needing isolation of each type	L	1.1L 1.2L 1.3L
Articles containing only extremely insensitive substances	N	1.6N
Substance or article so packed or designed that any hazardous effects arising from accidental functioning are limited to the extent that they do not significantly hinder or prohibit firefighting or other emergency response efforts in the immediate vicinity of the package	S	1.4S

[10] 49 CFR 173.52 Classification codes and compatibility groups of explosives

3.3 Specifically Prohibited Wastes

The facility is prohibited from treating hazardous waste except for open burning of explosives, waste with a potential to detonate, and propellants for which there is no other safe mode of disposal. Specifically prohibited are chemical and biological munitions, their residues and packaging, radioactive materials, infectious waste, mercury containing waste, propellants for aerosol cans, and propellants not in their original package.

4. PREVIOUS REVIEWS OF ALTERNATIVES TO OBOD

There have been a number of reviews that have addressed alternatives to OBOD of energetic materials. The most recent have been in conjunction with the selection of technologies for the disposal of the M-6 gun propellant at Camp Minden. Stratta reviewed alternative technology for the disposal of energetics produced at the Army ammunition depots that was being open burned.[11] This report summarized size reduction and studies on triple base and double base propellants for further processing using non-thermal treatment technologies including cryogenic cutting with high pressure (60,000 psi) LN_2, hydromilling with high pressure (55,000 psi) water and supercritical CO_2 extraction. The report also reviewed the non-thermal treatment technologies alkaline hydrolysis, high temperature oxidation (supercritical water oxidation – SCWO), wet air oxidation (WAO), biodegradation and electrochemical reduction. Both hydromilling and cryogenic cutting were determined to be effective techniques for size reduction of energetic materials for treatment. While this report focused on non-thermal methods, they would have relevance for thermal treatment technologies where size reduction is required. Supercritical CO_2 extraction was not found to be effective for preparing propellants for non-thermal treatment. Only nitroglycerin was extracted leaving nitrocellulose and nitroguanidine behind. The conclusion of the review for the non-thermal treatment technologies is given in Table 5.

Table 5. Non-Thermal Technologies Review by Stratta et al [11]

Technology	Effectiveness	Gaps
Super Critical Water Oxidation	1. Achieved %99.991 destruction of triple-base propellant	1. Studies on other EM required 2. Solve plugging problems 3. Identify reaction products
Wet Air Oxidation	1. Treated EM pretreated by hydrolysis 2. Potential technology for biodegradation	1. Studies on other EM required 2. Requires study of materials of construction 3. pH, temperatures ranges 4. Range of oxidants
Electrochemical	1. Demonstrated ability to reduce some EM	1. Limited information 2. Requires much more research on electrode materials, reaction rates and byproducts.
Composting	1. Some literature report success with composting EM	1. Require more pilot studies 2. Pretreatment technologies such as size reduction and hydrolysis

[11] Stratta, J. Schneider, N.R., Weber, R.A., Donahue, B.A., (1998) Alternative to Open Burning/Open Detonation for Energetic Materials – A survey of Current Technologies, TR98/104 US Army Construction Engineering Research Laboratory (CERL)

Radford Army Ammunition Plant (RFAAP) performed a review of alternatives to open burning of contaminated energetic materials from the manufacturing processes that contain foreign object debris (FOD).[12] The alternative technologies assessed included those recommended by the Virginia Department of Environmental Quality from the above CERL review, technologies approved by the Department of Defense Explosive Safety Board (DDESB), and a few processes that were undergoing pilot-scale testing. It should be noted that the DDESB recommendation is limited to the explosive safety aspects of the specific technology not to its effectiveness.[13] At RFAAP, off specification and clean propellants and other energetic materials are sent to an incinerator; however, during a recent 2-year period over 15 tons per month were destroyed at the RFAAP open burning grounds due to safety hazards in preparing the contaminated EM for incineration. The RFAAP assessment included a literature review to develop a weighted-criterion for comparing the individual technologies against the baseline open burning. The criteria include:

- **Safety Hazards** during pre-treatment, treatment and post-treatment
- Flexibility and support required to handle **waste variability**
- Intermittent and quasi-instantaneous **environmental releases** that are hard to monitor and model
- Ease of managing treatment through **engineering controls** and maintenance
- Flexibility in **layout possibilities** without violating DOT and DOD MIL STD-286 arc tables
- **Support** in answering tough questions about the technology

In the assessment, each technology was given a rating for each criterion from -3 to +3 with 0 equal to open burning. The technologies determined mature enough to assess in the review included:

1. Supercritical Water Oxidation (SCWO) or High temperature Oxidation (HTO)
2. Donovon Controlled Detonation Chamber
3. APE 1236 Deactivation Furnace
4. Dynasafe Static Detonation Chamber
5. DAVINCH Vacuum-Integrated Detonation Chamber
6. Explosive Destruction System
7. ARCTECH Actomil Treatment Technology
8. Decineration Rotary Furnace System

Other technologies discussed but not rated were the Tactical Missile Demilitarization (TMD) unit at Letterkenny Army Depot, plasma arc pyrolysis, and molten salt oxidation. The TMD was not approved by the DDESB for bulk propellants so was not considered a viable technology. A plasma arc system had been tested by the US Navy for liquids and some solids such as wood, soils, and dunnage but the solids were required to be less than 15 microns in diameter. No energetic materials had been tested and the program was put on hold.

Pilot-scale studies of EM destruction were conducted using the Molten Salt Oxidation (MSO) at Lawrence Livermore National Laboratory (LLNL) and bench-scale experiments were conducted at the Naval Surface Warfare Center in the 1990s. Issues identified in these studies included difficulty keeping the salt dry due to condensation of water, a need to increase the oxidizing potential by adding nitrates, poor oxidation of cotton, paper and plastics, and assuring the ternary eutectic melts occurs. A 2011 review of MSO by Yao *et al* found that significant research is needed to (1) verify DRE, refine salt handling, and resolve issues

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[12] Radford Army Ammunition Plant, (2015) Alternative Technologies to Open Burning of Propellants, www.deq.virginia.gov

[13] DOD Defense Explosive Safety Board, (2015) Defense Explosive Safety Board (DDESB) Role in Approving Demilitarization Technology for Ammunition and Explosives (AE) Information Paper.

with materials and scale up; (2) Determine the effects of temperature, gas hold-up and oxidizing gas feed rate on DRE; and (3) develop more detailed information on economics.[14]

The final weighted evaluations of each technology compared to the baseline status quo open burning are shown in Table 6. According to the assessment, none of the technologies ranked above open burning with the highest rated technology being the APE 1236 furnace.

Table 6. Weighted Decision Matrix for Technologies to Treat FOD Contaminated Propellant [12]

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

A number of technologies evaluated were judged negatively because they were not recommended for bulk propellants or the batch system had low throughputs. Others were given positive ratings because of their pollution abatement system. A summary of the weaknesses and the strengths identified for the individual technologies is shown in Table 8.

[14] Yo,Z., Li, J., and Zhao, X., (2011) Molten Salt Oxidation: A versatile and promising technology for the destruction of organic-containing wastes, Chemosphere, 84(9), 1167 - 1174

Table 7. Strengths and Weakness Identified in the RFAAP Analysis of Alternatives for Open Burning [12]

Technology	Weaknesses	Strengths
Supercritical Water Oxidation	1. Requires segregation of propellants 2. Requires size reduction 3. High maintenance required	1. Waste stream can be fed to standard waste treatment plant
Donovan Chamber	1. Requires extra explosives 2. Not design for bulk propellants	1. Off gases can be treated 2. Minimal engineering controls needed 3. Well understood
APE-1236 Furnace	1. Only 1-2 lbs hand fed in batch process 2. Not design for bulk propellants	1. Off gases can be treated 2. Incineration-type engineering controls 3. Well understood
Static Detonation Chamber	1. Batch process limited to 5.3 lbs TNT equivalent 2. Only 30 lbs of propellant had been tested	1. Off gas are treated by separate unit 2. Well understood
DAVINCH	1. Batch process treating 68 lbs TNT equivalent resulting in high personnel exposure 2. Requires extra explosives (40% of load)	1. Off gases are treated with a cold plasma unit
Explosive Destruction System	1. Batch process treating up to 9 lbs TNT equivalent 2. Only one detonation/day 3. Requires cutting charges	1. Containment vessel contains fragments 2. All gas and liquid can be monitored prior to release
Actomil	1. Need consistent feed stream 2. Requires strict control of pH, alkalinity, temperature, and a minimum of 6 hours to eliminate explosive properties	1. Uses off-the-shelf equipment 2. Applied research continues on technology

A comprehensive review of technologies for the demilitarization and disposal of munitions was conducted by the Munitions Safety Information Analysis Center of NATO.[15] This report reviewed disassembly and removal techniques and destruction technologies. The report listed the technologies shown in Table 9, along with a description and the maturity of the system. The review was performed in 2006 so the technical maturity of some technologies may currently be higher than indicated.

[15] Wilkinson, J. and Watt , D. (2006) Review of Demilitarization and Disposal Techniques for Munitions and Related Materials, NATO Munitions Safety Information Analysis Center Report L-119

Table 8. Matrix of Demilitarization Technologies [15]

Technology	Description	Maturity
Open Burn	Uncontained burning of non-detonable items	Widespread use
Open Detonation	Uncontained detonation with donor charge	Widespread use
Contained Detonation	Detonation with donor charge in a container	In use
Contained Burn	Ignition and burning of non-detonable items in a chamber	Prototype
Incineration – Static Kiln	Incineration in sealed chamber (burn or detonate)	In use
Incineration – Rotary Kiln	Incineration with items moving through the kiln	Widespread use
Incineration – Car Bottom	Incineration with movable car to insert waste	Widespread use
Incineration – Fluidized Bed	Incineration with movable solid slurry to retain heat and improve combustion	Available
Incineration – Plasma Arc	Molten slag is heated by torch and destroys explosives	In use
Molten Metal Pyrolysis	Decomposition in a molten salt bath	Research
Oxidation Alkaline Hydrolysis	Hydrolysis at moderate temperatures and pressures with strong base	Prototype
Oxidation Actodemil	Hydrolysis at moderate temperatures and pressures with strong base and humic acid	In use
Oxidation Molten Salt	Oxidation with molten carbonate	Prototype
Oxidation Electrochemical	Oxidation in a electrochemical cell	Research
Oxidation Wet Air	Oxidation by oxygen at high temperatures (320°C) and high pressures (22 MPa)	Available
Oxidation Supercritical Water	Oxidation at water supercritical temperature (374°C) and pressure (22 MPa)	Prototype
Oxidation Direct Chemical	Oxidation by peroxysulfate at moderate temperatures and pressures	Research
Oxidation Adams Sulfur	Oxidation by elemental sulfur at elevated temperature and ambient pressure	Research
Oxidation Photocatalytic	Oxidation by UV light and catalyst	Research
Biodegradation aqueous slurry	Biodegradation by microbes in bioreactor	In use
Biodegradation, Enzyme	Biodegradation using enzyme catalyst	Research
Biodegradation GAC-FBR	Biodegradation in activated carbon and fluidized bed bioreactor	Prototype

5. ENERGETIC MATERIAL DISPOSAL

5.1 Disposal Processes

Most assessments of destruction technology have been associated with either the demilitarization of ammunition and munitions and the destruction of bulk explosives and propellants. Few, if any, assessments have been completed on processes for handling the wide variety of waste streams accepted at the Colfax facility. Defense Research and Development Canada reviewed technologies including open burn and open detonation (OBOD) as part of their RIGHTTRAC project to understand the life cycle costs of munitions including demilitarization ("design for demil").[16] While the waste stream has differences, the processes

[16] Poulin, I., (2010) Literature review on the demilitarization of munitions, TM – 2010-213, Defense R&D Canada - Valcartier

involved are similar. All destruction technologies require the same functions shown in Figure 10, with some requiring more preparation than others.

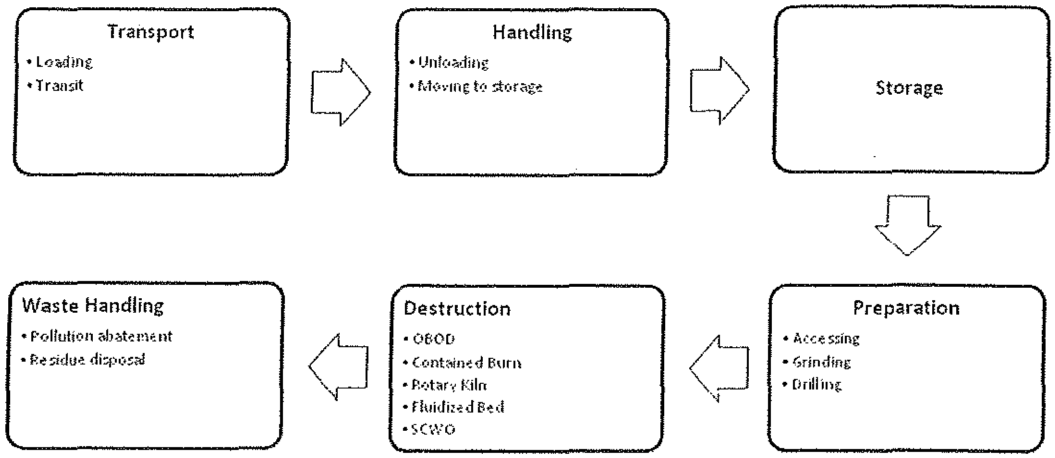

Figure 10. Functions Required in Processing of Waste Explosives

Most waste explosives will arrive in some sort of packaging that must be removed and disposed. This material (paper, drums, pallets, plastics, casings) should be separated from the hazardous waste when feasible to enhance recycle and reduce disposal volume and cost.

The hazards associated with disposing of explosive waste begins at the generator and continues through the transport, handling, storage, preparation, destruction, and concluding with the disposal of the residue. Some risks are unique to a particular destruction technology while others such as transport, handling and storage may be common to all technologies. For some technologies and particular waste streams, the preparation function may be extensive while for others the waste may be processed as received with little or no activities associated with accessing the explosive constituents for destruction.

The hazards associated with disposing of explosive waste were reviewed in a Danish report that analyzed six different techniques for disposing of decommissioned ammunition.[17] The technologies reviewed included open burn, open detonation, closed detonation, fluidized bed combustion, rotary kiln, and mobile furnace as shown in Table 10. The predominant risks for all technologies were:

- Premature ignition during handling, storage, or preparation due to sensitive detonators triggered by thunderstorm, static electricity, mobile phones, or mechanical sensitivity
- Incomplete destruction
- Fire in storage bunkers

The primary factor in determining the risk was the number of person-hours required for 1 kg of energetic material. The environmental risks for OBOD were not evaluated since they assumed the residual would be left in place rather than disposed of in a permitted facility. The following section summarizes some of the risk factors in explosive disposal.

[17] Duijm, N.J., (2002) Hazards Analysis of technologies for disposing explosive waste, Jor. Haz. Mater., A90, 123 - 135

Table 9. Hazards Associated with Specific Technologies [17]

Technology	Specific Hazards
Open Burn Open Detonation	• Air and soil pollution due to lack of pollution abatement system • Inaccurate preparation, insufficient accelerant or detonators • Fire in local vegetation
Closed detonation	• Catastrophic failure of pollution abatement system due to over pressurization
Fluidized Bed Combustion	• Pollution attributed to high pressure wash out of munitions
Rotary Kiln	• Pollution attributed to high pressure wash out of munitions
Mobile Furnace	• Catastrophic failure of pollution abatement system to over pressurization

5.2 Transportation

The U.S. consumes more than 5 billion pounds of commercial explosives annually, which results in as many as 500,000 shipments.[18] A recent search of the Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Agency incident data base from 2000 to 2016 showed a large number of incidents with explosives; however, the vast majority were due to mishandling, improper packaging, or undeclared hazardous material (ammunition and fireworks).[19] Of the 548 incidents report, only 2 resulted in fatalities and those involved fireworks during loading or unloading. Three other incidents resulted in non-hospital injuries. Two were related to loading primers and ammunition into vehicles and the other occurred when a driver lost control and the tractor trailer overturned with 35,000 boosters without detonators (UN0042) on board. The driver was rescued and the load exploded while people were in the process of evacuating. There were no incidents that involved transport of explosive waste. The safety record is attributed to incremental safety enhancements, the application of risk management by the government, commercial manufacturers, customers, and transportation companies.[20] A 1992 report that reviewed the historical accident records for incidents involving explosives in the United Kingdom established that a number of crashes or collisions with explosives involved occurred; however, none resulted in explosions. In the 40 years they identified only one railway fire and one roadway fire that were due to unsafe packaging of the explosives or explosives out of specification. The calculated rates of occurrence shown in Table 11 are based on this historical data and fault tree analysis.[21]

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[18] Visual Risk Technologies, (2013) Hazardous Materials Transportation Risk Assessment: State of the Practice, National Academy Press

[19] Pipeline and Hazardous Materials Safety Administration, Office of Hazardous Material Safety, (2016) Incident Report Database (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/Welcome.aspx)

[20] U.S. Department of Transportation, (2003) Intermodal Explosives Working Group Report

[21] Williamson, G.E., (1992) Risks from the Transport of Explosives, ADA 260984 Vol., 1 28th Explosive Safety Seminar, Anaheim CA 18 – 20 August 1992

Table 10. Derived Rate of Occurrences of Explosive Events [21]

Mechanism	Rail (km^{-1})	Vehicle (km^{-1})
Unsafe Explosives	1×10^{-9}	1×10^{-9}
Fire	6×10^{-10}	2×10^{-9}
Impact	1×10^{-10}	2×10^{-10}

The risks during transport of explosive waste could be due to accidents, improper packaging, and misprofiling (shipping sensitive explosives). Assuming the destruction facility is situated within the confines of the current treatment unit, the transportation risks would generally be independent of the selected destruction technology. Risk would be proportional to the throughput of the facility relative to the current permit limit of 561,700 pounds/year net explosive weight (NEW).

5.3 Handling

The Colfax facility accepts the waste based on their experience with the generators and the waste profiles they are provided. The paperwork for each incoming shipment is processed at the office in the front of the facility, and the waste is then transferred to storage magazines without further inspection or processed the same day it arrives without going into storage unless there is some indication there is a mismatch between the shipment and the profile from the generator. The handling risk occurs from dropping, ramming the package with a fork lift, or other mishap. Further handling is required when transferring from the storage magazines to the preparation building, and then to the thermal treatment unit.

5.4 Preparation

Understanding the preparation required prior to destruction is an important parameter in evaluating the relative merits of each alternative technology. Increased handling needed to perform disassembly, size reduction, grinding, drilling, dissolution, oxidation, or conversion prior to destruction increases risk, complexity, the number of unit processes in the system, and therefore, the cost of construction, operations and maintenance. For many technologies, some aspect of disassembly, defusing, projectile removal, and/or size reduction is required prior to destruction to remain below NEW limits, prevent detonations, provide access to the energetics, or minimize generation of large fragments.

Disassembly is required for many munitions to separate projectiles from explosives, remove fuses and primers from munitions and igniters from propellants. Army depots, commercial disposal facilities under contract to the Army, and large demilitarization operations, such as at the chemical agent demilitarization facilities, process thousands of the same and/or similar munitions and can invest the capital to use reverse assembly for increased productivity. In some cases, the explosives can be extracted for reuse through melting, water jet, or cyrofracture washout. At a waste disposal facility, there is no volume of specific munitions to justify the installation of mechanical systems to disassemble the variety of devices that are in the waste stream so customized techniques must be developed and the operators must rely on expertise and experience to safely and effectively process the munitions and energetic devices.

The amount of preparation required prior to destruction will depend on the specific item and the degree of access to energetic material required for the type of destruction technology, even OBOD. For some technologies such as hydrolysis, SCWO, WAO, the aqueous solution must have intimate contact with the energetic material, the explosive or propellant must be in relatively small particles as destruction rate is a function of the surface area exposed, and metal casing and components must be treated separately. For other destruction technologies, minimal preparation other than simple size reduction or sectioning may be required prior to processing. There are a variety of techniques to accomplish size reduction or provide access including mechanical sawing, underwater sawing, bomb ring cutters, drilling, liquid jet cutting and cyrofracture.

Mechanical sawing has the advantage of flexibility for small number of dissimilar munitions or devices but caution needs to be taken to avoid detonation due to sparking, impact or friction. Water-cooling and/or underwater sawing can minimize the sparking and heat generated by friction and the feed rate should be less than 2.9 in/minute. Drilling should be conducted with coolant directed to explosive/cutting edge and drills over 1/4 inches require coolant channels. Pulsating pressure coolant supplies should be used on drills 1/4 inch or less.[22]

Fluid jets use high-pressure fluids to cut through or ablate materials, and to cut and section munitions or reduce the size of uncased energetics. Fluid jets use either abrasive or nonabrasive media and the carrier can be water, ammonia, or liquid nitrogen and operate at pressures up to 410 MPa at velocities as high as 1000 m/sec.[15] Fluid jet cutting is a relative safe operation as the water cools the metals and possible ignition of the explosive is suppressed.[16] Although there are potential hazards in the use of high pressure fluid jets such as impact, electrostatic discharge, mechanical sparking, and there may be post processing reactions of the fluid and components of the munitions, these hazards can be dealt with by careful design and practice. Performing the cutting under water reduces noise, minimizes distribution of the debris and abrasive and avoids sparking but creates more explosive contaminated waste water.[23] Fluid jet cutting has been used on many different caliber munitions from 20 millimeter to bombs, pyrotechnics, flares, mortars, and on very sensitive parts such as a fuses and igniters without adverse reactions.[16] Gradient Technology sells a fully contained system for munitions demilitarization that have been field tested and used by the military for everything from blasting caps to 2000 lb bombs and some integrate a chemical conversion system to handle the residual explosives from the cutting operation.[24]

Cryofracture involves cooling the munition in a liquid nitrogen bath for up to four hours and then fracturing or crushing the embrittled item in a hydraulic shear machine or press. Because the cryofractured debris burns rather than detonates, it reduces risks during thermal treatment and provides ready access to the energetics for SWCO and other solvent based systems. The General Atomics (GA) robotic cyrofracture system was validated with a large number of munitions at Dugway Proving Grounds.[25] The GA system sectioned or disassembled ammunition greater than 20 mm prior to feeding to the APE 1236 rotary kilns at Army Ammunition Plants such as McAlester Army Ammunition Plant (MCAAF) and Tooele Army Depot (TEAD). The deactivation facilities include a Munitions Cryofracture Demilitarization Facility (MCDF) that freezes, fractures, punches, and exposes the energetic material prior to delivering it to the incineration system.[26] A schematic of the GA system is shown in Figure 11.

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22 US Department of Energy, (2012) DOE Standard Explosive Safety, DOE-STD-1212-2012

23 van Ham, N.H.A. (1997) Recycle and Disposal of Munitions and Explosives, Waste Management, 17 (2-3), 147 - 150

24 Gradient Technology, (2016) Munition Demilitarization, HTTP://gradtech.com/Demil.html

25 Follin, J. F. and Lute, A. (2000) Cryofracture Demilitarization of Munitions Phase II, Contractor Report ARWEC-CR-00001 AD-E-402906

26 Oklahoma Department of Environmental Quality (2006) Permit 2005-301, McAlester Army Ammunition Plant (MCAAP) Munitions Deactivation Furnace

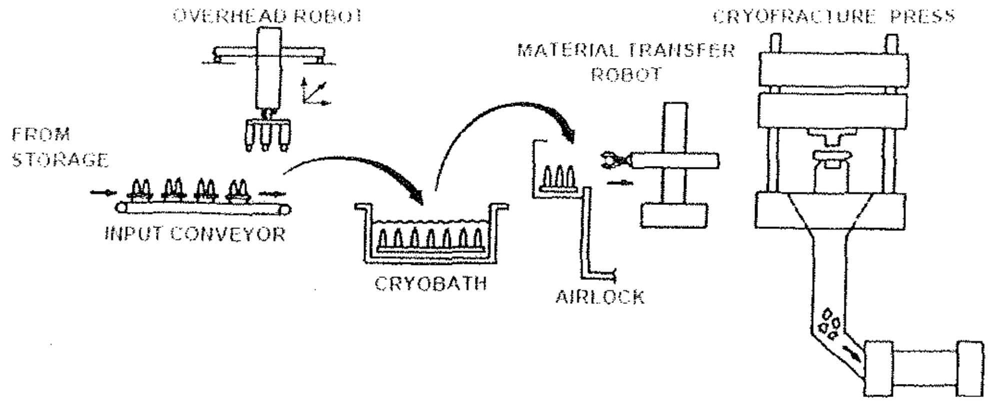

Figure 11. GA Cyrofracture System Schematic [25]

Detonations in the cryofracture press are minimized by controlling the orientation of the device, however, replaceable fragment shields are in place and the press is designed to withstand multiple detonations.[27]

6. DESTRUCTION TECHNOLOGIES

Numerous thermal, detonation, and oxidation technologies have been successful in the destruction of explosives and propellants. These have been reviewed for a number of applications, the most recent being the destruction of 15,000,000 lbs of M-6 at Camp Minden, Louisiana. There are advantages and disadvantages of each technology depending on the application, and specifically on the variety of the energetic waste stream. The following will describe some of the potential alternatives that deserve consideration in the selection of technologies to replace OBOD.

6.1 Open Burn Open Detonation

Open burn and open detonation (OBOD) is an efficient and inexpensive technique for destruction of a broad range of explosives, propellants, and ammunitions, particularly for less developed countries with neither substantial fiscal resources nor expertise and infrastructure for sophisticated technology alternatives. Most alternative technologies are best suited to well defined, stable, undegraded ammunition in environments where experienced and trained operators are available to handle, disassemble and remove the explosive prior to disposal. However, OBOD is banned in a number of countries and some restrict its use to manufacturers.[15] OBOD is generally discouraged since the alternative technologies are deemed to be more protective of safety, health, and the environment. While most industrialized countries have the fiscal resources, skills, and infrastructure to construct and operate high technology alternatives, many developing and underdeveloped countries do not. Yet many of these countries have widely dispersed, poorly inventoried, and degrading explosive stockpiles, and have neither the resources to build and operate dispersed disposal facilities, nor the transportation infrastructure to transfer these energetic materials to a centralized destruction facility. Since both the countries responsible for the energetics and the agencies and countries assisting them in disposal had concerns with the potential human health and environmental effects of OBOD and this was causing delays in the disposal of many dispersed stockpiles.[28] In the United States, OBOD is limited to reactive, ignitable wastes, and energetic wastes that cannot be safely disposed of through other modes of treatment.[29] These wastes include EPA Hazardous waste Code D003 (reactivity) and include propellants, explosives, pyrotechnics, and munitions under the Military Munitions Rules.

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[27] Follin, J.F. (2015) The Cryofracture Demilitarization Process: A Evolving Technology, 2007 Global Demilitarization Symposium and Exhibition, Las Vegas NV

[28] South Eastern European Clearinghouse for the Control of Small Arms and Light Weapons, (2004) (SALW) Destruction – Environmental Releases for Open Burning and Open Detonation (OD) Events

[29] 40 CFR 265.382 Open Burning; Waste Explosives

There are twelve government sites permitted and eight more with interim permits for OBOD of hazardous waste. CHC is the only commercial facility permitted to OBOD waste energetic materials.[30]

6.1.1 OBOD Emissions

The Southeastern European Clearinghouse for the Control of Small Arms and Light Weapons (SEESAC) was assisting many of the smaller Eastern European counties and was concerned that the uncertainty in health and environmental effects was delaying disposal. Air emissions from OBOD are by their character uncontrolled; however, a major effort was undertaken by SEESAC to create an OBOD database. This study conducted by Dr. Bill Mitchell of Bill Mitchell Associates was a follow-on to previous compilations by the Environmental Protection Agency (EPA), the US Army Defense Ammunition Center, and Chemical Compliance Systems Inc. (CCS) efforts to better define the emissions from OBOD at Army ranges and facilities.[31] The conclusions from the EPA report were:

1. OBOD can be an environmentally safe way to dispose of excess energetics that cannot be recycled or safely moved.
2. OB of EM with fuel and wood with plastics or other chlorine containing materials should be avoided to minimize the potential for dioxin and furan formation
3. OB and OD produce the same predominant emission products
4. The emissions from OBOD can be adequately represented by the following 17 constituents: CO_2, CO, NO, NO_2, N_2, H_2O, ethane, propane, i-butane, n-butane, acetylene, ethylene, propene, benzene, toluene, particulate matter and metals
5. No molecules were found larger than the parent energetics with the exception of naphthalene and its alkylated sister products; therefore, polycyclic aromatics containing three or more rings are unlikely to be found.
6. Most emission products are naturally occurring in the environment
7. Emission factors based on mass of emission product/kg of net explosive weight (NEW) are unusable in risk assessment

6.1.2 Environmental Fate Factor

One of the most important features of the new CCS and US Army initiative was the creation of the Environmental Fate Factor (EFF) to replace the traditional emission factor (EF) based on the net explosive weight (NEW) or net explosive quantity (NEQ). These EFs were developed by the mining industry for the explosives such as dynamite, ammonium nitrate and fuel oil (ANFO), and only characterized the simple inorganic gases rather than the constituents of concern for environmental risk assessment such as Persistent Organic Pollutants (POP) and heavy metals (i.e. cadmium, barium, lead, and mercury). The EFF was derived by multiplying the traditional emission factor based on the NEW (kg lead/per kg NEQ) by the average NEW burned or detonated in the tests in the database divided by the mass of the relevant species in the ammunition. This new EFF database provides the tool to (1) identify those EM that can be destroyed by OBOD without endangering human health or the environment, (2) prioritize destruction of those stockpiles posing the highest risk, (3) eliminate those items that are unsuitable for OBOD, and (4) provide the basis for environmental impact and health risk assessments.[28]

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[30] EPA https://www.epa.gov/hwpermitting/list-example-hazardous-waste-permits-open-burning-and-open-detonation

[31] Mitchell, W.J. and Suggs, J.C., (1998) Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD), EPA Report Number EPA/600/R-98/103

The EF and EFF determined relevant for performing risk assessments for OBOD are shown in Table 11.

Table 11. Recommended EF and EFF for EIA and HRA [28]

Emission Product	EF/EFF Units	OB	OD
Particulate matter (PM)	kg PM / kg NEQ	1.1E-02	9.3E+00
SO_2	kg SO_2 / kg NEQ	1.2E-03	5.0E-04
Energetics	kg Energetic X/kg Energetic X in EM	1.4E-06	2.8E-04
Metals- Casings	kg Metal X /kg Metal X in EM	1.1E-02 1	1.1E-02
Metals -Coatings	kg Metal X /kg Metal X in EM	1.0E-01 1	1.0E-01
Metals -Energetics	kg Metal X /kg Metal X in EM	3.1E-01	1.1E-01
CO	kg CO/ kg C in EM	7.4E-03	7.4E-02
NOx (as NO_2)	kg NO_2 / kg N in EM	6.2E-02	4.8E-02
Chloride (As HCl)	kg HCl / kg Cl in EM	9.2E-01	1.2E-01
Aromatics (As Benzene)	kg Benzene / kg C in EM	6.1E-05	3.1E-04
Saturated HC (As Ethane)	kg Ethane / kg C in EM	1.9E-05	1.5E-02
Unsaturated HC (As Ethylene)	kg Ethylene / kg C in EM	3.8E-04	1.4E-03
Methane	kg Methane / kg C in EM	5.5E-04	2.3E-03
PAHs (as Naphthalene)	kg Naphthalene / kg C in EM	2.7E-06	2.0E-5
PCDD/ PCDF (as TEQ)	kg TEQ / kg NEQ	2.0E-12	2.0E-12

Note: 1. No emissions data available. OD value used as default.

To use the EFF in assessments, the components of the specific items are required. For ammunition, this detailed description can be found in the US Army Munitions Inventory Disposal Action System (MIDAS) database. Unfortunately, access to this database is restricted but other sources may be used. An example of use of the database to calculate emissions from OD of a M3747A Mortar (fuse removed) using a 20 kg of donor charge is given in Table 12.

Table 12. Estimated Emissions into the Plume from Open Detonation of a M3747A Mortar [28]

Input Parameter / Emission Product	kg Detonated	EF / EFF Value	kg Released Into Plume
PM	-	9.3 kg / kg NEQ	1073.00000 kg
SO_2	-	5.0E-04 kg / kg NEQ	0.05800 kg
CO	-	7.4E-02 kg / kg C	2.50000 kg
NOx	-	4.8E-02 kg / kg N	1.60000 kg
Aromatics (As Benzene)	-	3.1E-04 kg / kg C	0.01000 kg
Saturated HC (As Ethane)	-	1.5E-02 kg / kg C	0.50000 kg
Unsaturated HC (As Ethylene)	-	1.4E-03 kg / kg C	0.04600 kg
PAHs (As Naphthalene)	-	2.0E-05 kg / kg C	0.00007 kg
METALS IN CASINGS			
Iron (Fe)	225.0 kg	1.0E-02 kg / kg	2.250 kg
Manganese (Mn)	4.0 kg	1.0E-02 kg / kg	0.040 kg
Aluminium (Al)	80.1 kg	1.0E-02 kg / kg	0.800 kg
Zinc (Zn)	1.2 kg	1.0E-02 kg / kg	0.012 kg
Copper (Cu)	3.6 kg	1.0E-02 kg / kg	0.036 kg
METALS IN COATINGS			
Zinc (Zn)	1.200 kg	1.1E-01 kg / kg	0.13000 kg
Cadmium (Cd)	0.012 kg	1.1E-01 kg / kg	0.00130 kg
Chromium (Cr)	0.006 kg	1.1E-01 kg / kg	0.00066 kg
METALS IN ENERGETICS			
Lead (Pb)	0.0010 kg	1.1E-01 kg / kg	0.00011 kg
ENERGETICS			
RDX	57.0 kg	2.8E-04 kg / kg	0.0160 kg
TNT	57.0 kg	2.8E-04 kg / kg	0.0160 kg
Nitrocellulose (NC)	6.0 kg	2.8E-04 kg / kg	0.0017 kg
Nitroglycerin (NG)	4.1 kg	2.8E-04 kg / kg	0.0011 kg

Note: For 100 x 81mm Mortar Bombs HE the NEQ = 115.4 kg, Total Carbon = 33.4 kg and Total Nitrogen = 33.7 kg.

Aurell *et al* measured the emissions from OBOD of munitions and rocket motors using an Aerostat carrying an instrument package at a height of 30–70 meters above the ground and distance of 100 meters downwind of the detonation site. The Aerostat was maneuvered to keep it in the plume. They measured the emissions from the detonation of four different explosives at varying depths of soil from the surface to 1.8 meters and the surface burning of five propellants.[32] The detonation of COMP B at the surface, as it would be at the Colfax facility, gave the emission factors shown in Table 13.

[32] Aurell, J., Gullett, B.K., Tabor, D., Williams, R.K., Mitchell, W., Kemme, M.R., (2015) Aerostat-based Sampling of Emissions from Open Burning and Open Detonation of Military Ordnance, Jor. Haz. Mater. 284, 108- 120

Table 13. Emission Factors from Open Detonation of COMP B [32]

Pollutant	Emission Factor
PM_{10} (g/g NEW)	0.29
$PM_{2.5}$ (g/g NEW)	0.42
HMX (g/g C)	5.0E-7
RDX (g/g C)	2.6E-6
TNT (g/g TNT)	1.7E-6
PETN (g/g C)	2.6E-7
Tetryl (g/g C)	ND
1,3,5-Trinitrobenzene	ND
1,3-Dinitrobenzene	ND
4-Amino-2,6-dinitrotoluene	ND
2-Amino-4,6-dinitrotoluene	1.0E-7
2,4-Dinitrotoluene	1.0E-6
3,5-Dinitrotoluene	ND

ND = nondetect

A comparison of the EF for PM from the South Eastern European Clearinghouse for the Control of Small Arms and Light Weapons data in Table 12 with that measured by Aurell (9.3 g/g NEW vs. 0.29 g/g NEW) shows that the SEESAC EF estimates may be conservative. Table 15 gives the measured EF for particulates and organic compounds from the open burning of two common rocket propellants: M31A1E1 and M26.

Table 14. Emission Factors for Open Burning of Propellants M31A1E1 and M26 [32]

Pollutant	Emission Factor M31A1E1	Emission Factor M26
PM_{10} (g/g NEW)	4.0E-3	1.1E-2
$PM_{2.5}$(g/g NEW)	3.6E-3	1.1E-2
Nitrobenzenes (g/g C)	4.0E-6	1.4E-7
Nitrotoluenes (g/g C)	2.7E-7	ND
Napthalene (g/g C)	6.7E-6	1.2E-7
Acenaphthylene (g/g C)	2.1E-7	2.9E-8
Acenapthene (g/g C)	1.2E-7	8.5E-9
Fluorene (g/g C)	5.9E-7	3.3E-8
Phenanthrene (g/g C)	6.1E-7	6.2E-8
Anthracene (g/g C)	4.8E-8	3.8E-9
Fluoranthene (g/g C)	8.2E-8	1.7E-8
Pyrene (g/g C)	6.4E-8	1.2E-8
Chrysene (g/g C)	ND	ND
Benzene (g/g C)	1.1E-5	1.1E-5
Toluene (g/g C)	2.3E-4	6.7E-6
Ethylbenzene (g/g C)	2.2E-5	9.8E-6
Xylenes (g/g C)	1.3E-4	2.5E-5
1,2,4-Trimethylbenzene (g/g C)	3.4E-5	1.4E-5

The organic EF are consistent with those reported by SEESAC in Table 11.

6.1.3 Comparison of OBOD Emission to Incineration

The SEESAQWE study compared the emissions from OBOD to those permitted to be discharged from explosive waste incinerators (EWI).[28,33] A comparison of 378 kg of M-9 propellant with the emission limits for EWI is shown in Table 15.

[33] 46 CFR Part 63, (2003) Interim Standards from Hazardous Air Pollutants from Hazardous Waste Combustors, February 12, 2003

Table 15. Comparison of Estimated Mass Emissions of OBOD of 378 kg M-9 Propellant with EWI Emission Limits over 8 Hours [28]

Emission Product or other Measure of Performance	Source	Emission Limit [1]	Kg Emitted Over 8-hr Period		
			EWI	OB	OD
%DRE (Energetics)	US	99.99%	0.038	0.0005	0.10
Total PM	EU	5.2 mg/m^3	13	4.2	3,520
SO_2 (including SO_3)	EU	16.7 mg/m^3	40	0.45	0.19
HCl	EU	3.3 mg/m^3	0	0	0
NOx (as NO_2 Equivalent)	EU	133 mg/m^3	320	3.5	2.7
CO	EU	16.7 mg/m^3	40	0.62	6.2
Dioxin/Furan as TEQ	EU	0.067 ng/m^3	1.6E-07	7.6E-10	7.6E-10
Total Toxic Metals, as Metal (Sb, As, Co, Pb, Cu, Mn, Cr, V, Ni)	EU	167 ug/m^3	NA	NA	NA
Cd + Tl	EU	16.7 ug/m^3	NA	NA	NA
Hg (as metal)	NA	16.7 ug/m^3	NA	NA	NA
LVM (As, Be, Cr)	US	32 ug/m^3	NA	NA	NA
SVM (Pb, Cd)	US	40 ug/m^3	NA	NA	NA

Dr. Mitchell's studies demonstrated through several examples that OBOD of ammunition meets incineration standards. A few caveats must be added to the use of EF or EFF to compare OBOD with incineration. The EWI emissions are released from the stack at 100 meters from the ground; whereas, the OBOD plumes can rise several hundred meters and undergo massive dilution before the plume constituents return to ground level; therefore, accurate comparisons require air dispersion and disposition modeling. There are a number of validated models for air dispersion from stacks and the Open Burn/Open Detonation (OBOD) Model developed by Dugway Proving Grounds that are available from the EPA[34]. Metals from casings and other components, not incorporated in the plume, will be deposited in the vicinity of the burn or detonation site. If toxic metals might leach from these items, their disposition should be addressed in runoff and soil environmental fate studies. Finally, the OBOD estimated emissions are compared to the incinerator emission standards and actual incinerator emissions that may be much less.

6.2 Contained Burn

Contained burn is analogous to open burn except the ignition takes place inside a containment vessel and the combustion gases are captured and treated in a pollution abatement system prior to release to the environment. Additional fuels are added to initiate combustion if the materials do not burn well on their own. The burn pan is then fed into the thermal treatment chamber and the material is ignited remotely. The exhaust gases are fed into a containment vessel which allows the exhaust gas to be fed to the pollution control system in a controlled manner.

Contained burn systems are not considered hazardous waste incinerators since they operate on the energy supplied by the energetic and any added accelerant as in open burn. Therefore, this alternative would be permitted under RCRA Subpart X as is the current Colfax OBOD. The most recent example of a contained burn system is the destruction system selected to destroy the M-6 propellant and clean burning igniters at Camp Minden. The El Dorado Engineering Inc. contained burn system selected is composed of a batch feed system, a vertical seal combustion chamber, and the effluent gas pollution abatement system shown in

[34] Bjorklund, J.R., Bowers, J.F. Dodd, G,C, and White, J.M. (1996) Open Burn/Open Detonation Dispersion Model (OBODM) User's Guide Vols. I and II, DGG –TR-96-008a and 008b, US Army Dugway Proving Ground UT

Figure 12. The contained burn system is designed for batches of 880 lbs of M-6 per batch and 2–3 cycles per hour.[35] In the contained burn process, the energetics to be destroyed are placed on a tray and inserted into the chamber; the chamber is closed and the energetics are ignited. M-6 can be ignited but some energetics may require auxiliary fuel to initiate combustion. Upon ignition, the propellant burns and the flames rise in the vertical chamber mixing with the air. The chamber temperature rises and after a sufficient residence time the gases are metered into the pollution abatement system consisting of two after burners, a cyclone, gas cooler, bag house filter, high efficiency particulate air (HEPA) filtration, selective non-catalytic reduction (SNCR) for nitrogen oxide (NO_x) control, and venting through an exhaust stack. The contained burn chamber is not designed to contain detonations, so all munitions must be prepared to avoid any high energy events or fed inside a "strongbox" to contain any fragments.

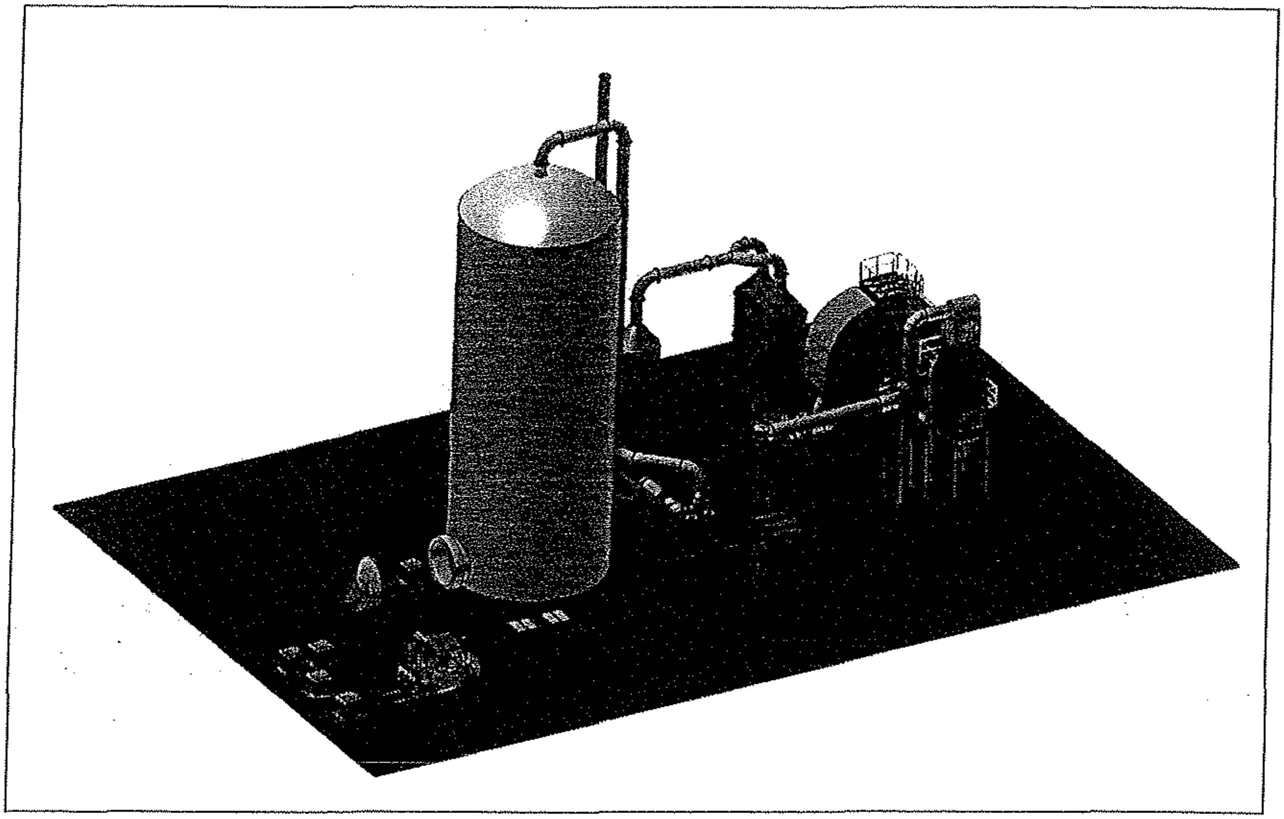

Figure 12. Proposed El Dorado Contained Burn System for Camp Minden M-6 Destruction [35]

Other contained burn systems such as the Tactical Demilitarization Development (TaDD) system are horizontal and designed to contain the static firing of rocket motors.

6.3 Contained Detonation

As contained burn is analogous to open burning, contained detonation is the alternative to open detonation occurring in a sealed vessel that is designed to handle the blast, fragments, and overpressure of the energetics and donor charge. As with contained burning, the contained detonation is a batch process in which the energetic to be destroyed is detonated by a donor charge and then the emissions are slowly released through a pollution abatement system. The CH2M Hill Controlled Detonation Chamber, earlier known as the Donovan Blast Chamber, is made of inner and outer layers of steel plate with sand in between

[35] Hayes, Bob, (2015) El Dorado Engineering Technology Inc. Propellant Disposal Technology, Presentation to the Camp Minden Dialog Evaluation Committee

and the floor has a layer of gravel. Replaceable wear plates of abrasion resistant steel are added to protect the interior walls and extend life.[36] Water bags are suspended from the ceiling to reduce heat damage to the chamber. When the chamber is opened, an exhaust fan pulls the exhaust gases through a scrubber or bag house. The donor to explosive ratio is 3:1 for smoke producing rounds, 2:1 for propellants, and 1:1 for bulk explosives. The DDESB approved limits for the transportable CH2M TC10 system is 13 lbs TNT equivalent, 16.7 lbs for the T25, and 40 lbs for the TC30/60. These systems are designed for transport to locations for the disposal of unexploded ordinance.[37]

The Kobe Steel DVINCH (Detonation of Ammunition in a Vacuum Integrated Chamber) is similar to the Controlled Detonation Chamber except the chamber is evacuated before the detonation to reduce the overpressure. The system was primarily designed to destroy chemical munitions and has been successful at a number of sites. The system is not intended for bulk propellants. A batch for the DV65 is limited to 65 lbs of TNT equivalent explosive of which 60% is the donor charge. There has been focus on the deployment of a transportable DVINCH.

The Dynasafe static kiln or Static Detonation Chamber (SDC) is represented in the US by UXB and is a combination of contained burn and contained detonation. The heat is provided by electricity with no open flame so it is not considered incineration. The static kiln uses heat to deflagrate or detonate the munitions in the double walled chamber designed to contain the blast and overpressure. As in the contained burn systems, the exhaust gas is treated in a pollution abatement system. The system has an automated feed and most munitions need no preparation. Dynasafe produces kilns with capacities from 10 kg to 40 kg NEW/hour.[38]

6.4 Hydrolysis of Explosives

Hydrolysis of explosives and propellants by high a concentration of caustic has been studied extensively as a technology for use in the USA chemical demilitarization program. In an extensive review of the literature over 16 years ago, the National Research Council found that one of the issues that needed further study was the simultaneous hydrolysis of different types of energetics and the potential for forming extremely sensitive or dangerous precipitates.[39] Energetic materials are produced in media from acids or salts of acids and are, therefore, susceptible to breakdown by hydrolysis. The composition of common energetics is shown in Table 16. Base hydrolysis converts the energetic material into organic and inorganic salts, soluble organics, and some gaseous products. The hydrolysis rates can be slow unless reactions are conducted at elevated temperatures between 60°C and 150°C under strong base conditions (15–25 wt% of NaOH). The relative rate of hydrolysis is nitroglycerin (NG) >TNT >tetryl ≥ RDX > HMX > nitrocellulose (NC). Caustics break down the energetic materials onto organic and inorganic salts, some soluble organics and various gases. Bonnett led a US Army sponsored pilot study of caustic hydrolysis of a range of propellants and explosives used in chemical munitions.[40] These are shown in Table 16.

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[36] Quimby, Jay, (2007) Current Status of the Transportable Controlled detonation Chambers Offered by CH2M Hill, Presented at the Global Demilitarization Exhibition and Symposium, Las Vega NV

[37] Young, Dan, (2010) Controlled Detonation Chamber (CDC) Safety, Presented at the 34th DDESB Safety Seminar, Portland OR

[38] UXB International Inc. (2016) Dynasafe Static Detonation Chamber (SDC) Demilitarization Units, www.UXB.com

[39] National Research Council, (1999) Review and Assessment of Alternative Technologies for the Demilitarization of Assembled Chemical Weapons, Appendix E. Neutralization of Energetic Materials by Hydrolysis, National Academies Press

[40] Bonnett, P.C. and Elmasri, E. (2002) Base Hydrolysis Process for the Destruction of Energetic Materials. Special Publication ARWEC-SP-01001

Table 16. Composition of Energetics used in Chemical Munitions [40]

Energetic Material	Composition
Tetryl	2,4,6 trinitrophenylmethylnitramine
Tetrytol	70% tetryl / 30% TNT
Composition B	60% RDX / 39% TNT / 1% wax
Composition B4	60% RDX / 39.5% TNT / 0.5% calcium silicate
M28 propellant	60.0% nitrocellulose / 23.8% nitroglycerin / 9.9% triacetin / 2.6% dimethylphthalate / 2.0% lead stearate / 1.7% 2-nitrodiphenylamine
M8 propellant	52.15% nitrocellulose / 43% nitroglycerin / 3% diethylphthalate / 1.25% potassium nitrate / 0.6% ethyl centralite
M1 propellant	84% nitrocellulose / 9% dinitrotoluene / 5% dibutyl phthalate / 1% diphenylamine / 1% lead carbonate

These energetics are similar to some of propellants and explosives identified in the Colfax facility waste stream and so the lessons learned from this study are relevant to the assessment of alternative destruction technology. The study found that the above energetics could be effectively decomposed at greater than 99.75% in 20% sodium hydroxide (NaOH) at 87°C in nine hours. The high temperature is also necessary due to the low aqueous solubility of some of the energetics such as TNT. The thermal runaway temperature was reported to be greater than 130°C. The resulting hydrolysate would require further treatment by some other technology and this may necessitate neutralization with a strong acid. A typical hydrolysate composition is shown in Table 17. The final hydrolysate has a high salt content, but also contains metals, organics, and cyanide. As shown in Table 18, gas generated during the reaction varied from 110 cm^3/g for propellants to 250 cm^3/g for tetrytol and Comp B. The composition of the gas that would also require treatment in a pollution abatement system included high concentrations of aromatic hydrocarbons, ammonia, and some trace explosives.

Table 17. Composition of CMP B Hydrolysate [40]

End of Run Hydrolysate Analysis				
Component	Concentration	Unit	ppm	Note
Acetate	3,680.00	mg/l	3,680.00	
Aluminum	1300	ug/l	1.30	J
Ammonia	1,380.00	mg/l	1,380.00	
Beryllium	3.8	ug/l	0.00	J
Calcium	24000	ug/l	24.00	J
Chromium	160	ug/l	0.16	J
Cobalt	200	ug/l	0.20	J
Copper	380	ug/l	0.38	J
Cyanide (Sodium Cyanide)	40,000.00	ug/l	40.00	
Formate	27,600.00	mg/l	27,600.00	
Iron	2700	ug/l	2.70	J
Lead	670	ug/l	0.67	J
Magnesium	5,920.00	ug/l	5.92	
Nitrite-N	123.00	mg/l	123.00	
Silver	85	ug/l	0.09	J
Sodium	62,200,000.00	ug/l	62,200.00	
Sulfate	149.00	mg/l	149.00	
TNT	24,940.00	ug/l	24.94	
Zinc	3,880.00	ug/l	3.88	
TIC	1,917.50	mg/l	1,917.50	
TOC	21,190.00	mg/l	21,190.00	
COD	56,000.00	mg/l	56,000.00	
Total Suspended Solids	170.00	mg/l	170.00	
Total Dissolved Solids	176,000.00	mg/l	176,000.00	
Normality as NaOH	1.15	n		
Density	1.12	g/ml		

J = Below detection limit - Estimate

Table 18. Reactor Off Gas Composition during COMP B Hydrolysis [40]

Reactor Off Gas Analysis					
Component	During Energetic Addition	Note	During Reaction	Note	Unit
1,3,5- Trinitrobenzene	37.30	MAX			ug/m^3
1,3-Dinitrobenzene	3.65	MAX			ug/m^3
2,4,6-Trinitrotoluene	6710.00	MAX			ug/m^3
2,4-Dinitrotoluene	124.00	MAX			ug/m^3
2,6-Dinitrotoluene	33.60	MAX			ug/m^3
2-Amino-4,6-Dinitrotoluene	37.30	MAX			ug/m^3
4-Amino-2,6-Dinitrotoluene	57.40	MAX			ug/m^3
Acetaldehyde	1350.00		69.10		ug/m^3
Acetone	552.00		404.00		ppbv
Ammonia	4110000.00		16,200,000.00		ug/m^3
Bromodichloroethane	20.00		13.80	U	ppbv
Butanal	87.70		29.70		ug/m^3
Carbon Dioxide	0.12		0.07		%
Carbon Monoxide	323.00		123.00		ppmv
Chloroform	16.10		13.80	U	ppbv
Crotonaldehyde	14.80		0.56	U	ug/m^3
Cyanide	0.01		0.01		ug/m^3
Cyclohexanone	6260.00	D	278.00		ug/m^3
Decanal	619.00		175.00		ug/m^3
Dibromochloromethane	20.50		13.80	U	ppbv
Formaldehyde	6870.00	D	347.00		ug/m^3
Heptanal	34.60		21.00		ug/m^3
Hexanal	40.00		29.10		ug/m^3
HMX	16.20	MAX			ug/m^3
Methylene Chloride	73.30	B	90.90	B	ppbv
m-Tolualdehyde	0.36	J	13.00		ug/m^3
Nitrous Oxide	18089.00		9,180.00		ppmv
Nonanal	47.10		22.60		ug/m^3
NOx	0.00		16.80		ppmv
Octanal	50.10		23.80		ug/m^3
Oxygen	18.90		20.00		%
Propanal	454.00		83.30		ug/m^3
RDX	3,690.00	MAX			ug/m^3
Toluene	12.70		13.80	U	ppbv
Total Hydrocarbons	42.60		47.90		ppmv

J = Estimated Value; concentration is below limit of quantification
MAX = Reported result was from a multi-fraction gas sampling train that contains both non-detected results and positive results
U = Analyte was not detected
D = Result was obtained from analysis of a dilution or surrogate were diluted below detection limit
B = When applied to anions or organic analysis the qualifier indicates that the analyte was detected in the associated method/instrument blank

The important conclusions from the study were:

1. DRE ranged from 99.75% for Tetrytol to 100% for all the energetics processed.
2. The hydrolysate was intrinsically safe except for a high pH (13-14).
3. Hydrolysate will require further treatment to destroy residual organics.

4. Optimal processing conditions were 20% (weight) sodium hydroxide, 87°C, 70-80 rpm agitator speed and a 9-hour processing time.
5. A feed rate up to 200 lbs/hr was achieved.
6. Gas generated during hydrolysis contained cyanide, benzene, ammonia, toluene and xylenes and will require scrubbing and treatment.
7. Energetics built up on the inside of the reactor.
8. Propellants and explosives can be processed together.
9. Particle size was not an important parameter as all the explosives were TNT-based and quickly collapsed at 87°C.
10. Cotton threads from propellant bundles clog pumps, filter and impellers.

6.5 Supercritical Water Oxidation

As noted above, hydrolysis requires a secondary treatment prior to ultimate disposal of the liquid hydrolysate. Hydrothermal oxidation or supercritical water oxidation (SCWO) is often proposed as technique for secondary treatment of residual organics in neutralized hydrolysate. SCWO oxidizes organics above the critical point of water (347°C) at temperatures above 650°C and pressures of 3400 psi. All feeds must be pumpable; therefore, propellants must be ground and mixed with water in a slurry before feeding directly to the SCWO. The low aqueous solubility of explosives and propellants generally requires a process such as base hydrolysis prior to treatment, particularly if the explosive or propellant is in a device or casing.[41] Although the SCWO vendor, General Atomics, says the effluent can be discharged to the sewer, generally the final liquid waste from these processes will still have high salt and suspended solids content and will require extensive treatment prior to discharge or transport and disposal in an industrial waste treatment facility. The SCWO system for treatment of chemical agent VX and energetic hydrolysate shown in the Blue Grass Chemical Agent Destruction Pilot Plant (BGCAPP) (Figure 13) incorporates an extensive water recovery system to recycle 70% of the liquid effluent back into the system as quench water.[42] This water reuse system still requires a disposal method for the high salt reject waste stream from the reverse osmosis unit. Gas emissions from the SCWO have low concentrations of SO_x, NO_x, and other toxic products such as dioxins; however, they may require some minor pollution abatement processes such as filtration.[43] Issues raised during an assessment of the SCWO system for BGCAPP by the National Research Council during their review of the First of a Kind (FOAK) testing included safety of maintaining nearby equipment during operation of the SCWO, cyanides in the energetics hydrolysate, managing the feed composition, training and knowledge of operators for this complex system, life-time of the titanium liner, corrosion thinning of the thermowells, and maintaining a water balance with the water recovery system .[44]

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[41] Buelow, S.J. *et al* (2002) Destruction of Energetic Materials in Supercritical Water, AFRL-ML-TY-2002-4522
[42] National Research Council, (2012) The Blue Grass Chemical Agent Destruction System Pilot Plant's Water Recovery System, National Academies Press
[43] Elliott, J., (2006) Update on the Demil Technology Programs at General Atomics, Global Demilitarization Conference
[44] National Research Council, (2013) Assessment of Supercritical Water Oxidation System Testing for the Blue Grass Chemical Agent Destruction Pilot Plant, National Academies Press.

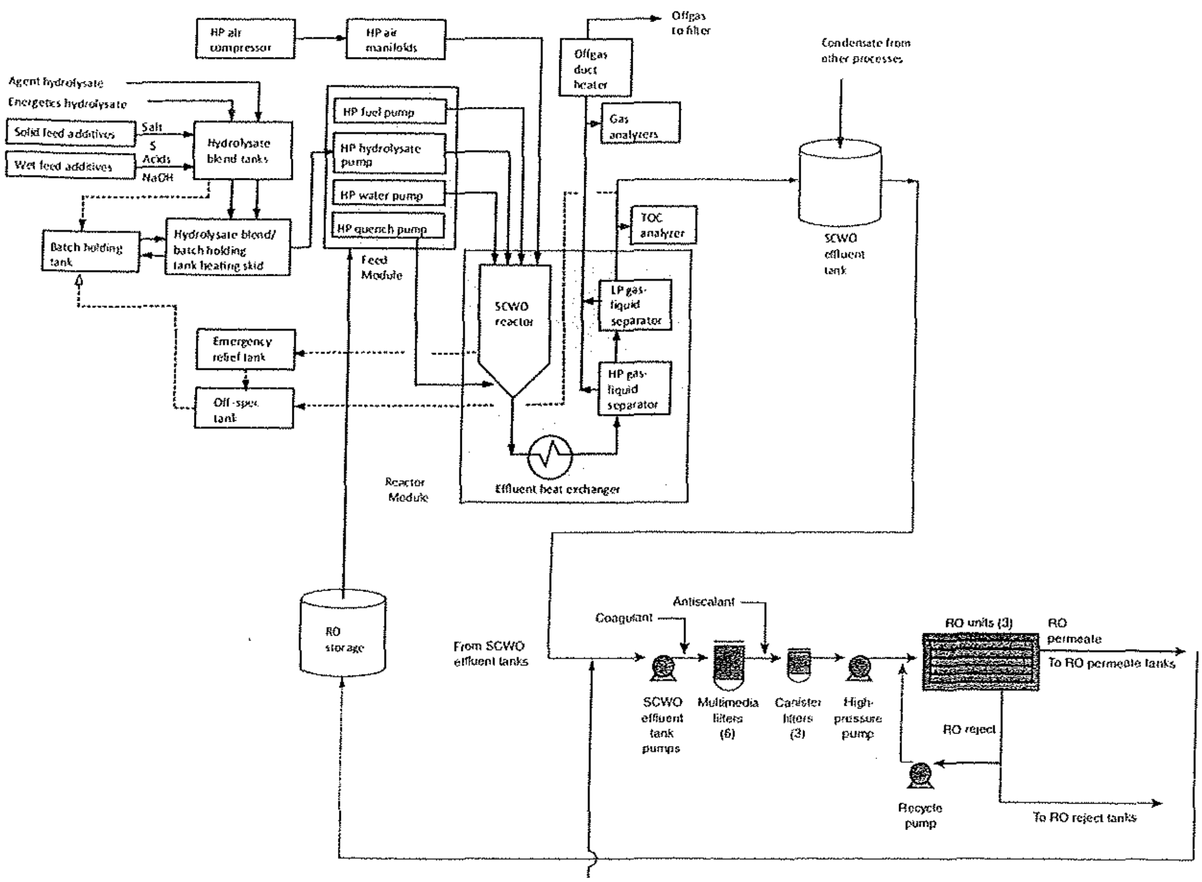

Figure 13. Flow Diagram of BGCAPP SCWO System and Reverse Osmosis Water Reuse System (WRS) [44]

6.6 Actodemil®

Actodemil® is an alkaline hydrolysis process which also includes humic/fulvic acid (ActoHAX™), a complex high molecular weight organic derived from lignite coal.[45] The process patented by Arctech takes place at moderate temperatures and atmospheric temperatures.[15] After neutralization with phosphoric acid, the final product is safe to use as a fertilizer. The process was successfully used to treat 20 tons of single-, double-, and triple-base propellant at McAlester Army Ammunition Plant and feasibility studies at a number of military installations and commercial facilities.[46] Applications include disposal of waste propellants and explosives, explosive contaminated waste, nitrocellulose fines, and other energetic wastes. According to Arctech, the humic acid enhances the reductive hydrolysis, adsorbs organics and nitrogen compounds, and produces an effective fertilizer with humic acid and mineral nutrients. According to a US Army white paper, "Under the alkaline reaction conditions of humic acid hydrolysis for propellants, the smaller carboxylate molecules are produced as a first step. These carboxylate groups react with phenolic and other hydroxyl groups in the humic acid and are incorporated into the humic acid molecule as esters.". [47,48] The Actodemil chemistry is shown in Figure 14.[49]

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[45] Arctech (2013) Humic Acid: A Review of Characteristics, Properties, Analytical Methods and Applications Technical Bulletin #5, Arctech, Chantilly VA www.arctech.com

[46] Arctech (2007) Actodemil Technology: A Novel Approach for Recycling Energetics into Fertilizer

[47] Kwak, Solim (2007) White Paper Demilitarization Facility Concept and Demilitarization of Propellants, Senior Science Advisor, Defense Ammunition Center

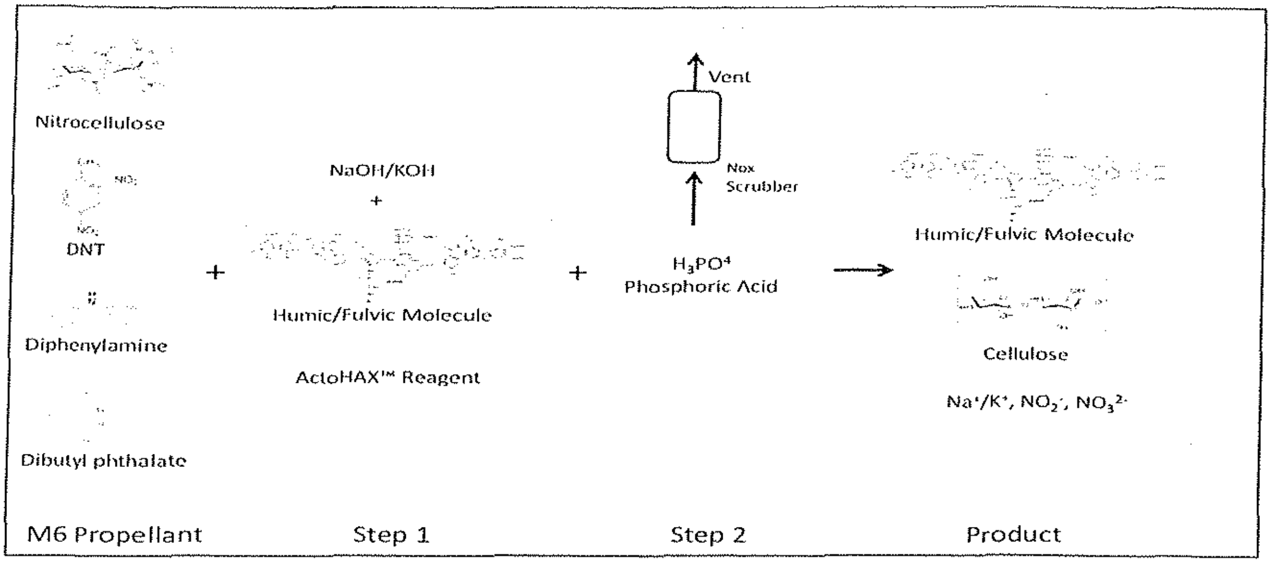

Figure 14. Actodemil® Process Chemistry for M-6 Propellant [49]

As with the other hydrolysis processes, the feed is introduced as a slurry (< 1 inch particle) which requires disassembly, grinding, and mixing with caustic. Units are available to process up to 2000 lbs/batch.[48] According to Arctech, the recycling of energetic to fertilizer meets the EPA Munitions Rule (40 CFR part 268.202), does not require a RCRA permit, and application of the final product to land is authorized as long as the Universal Treatment Standards (40 CFR Part 268.48), Toxicity Characteristic Leach Procedure requirements are met, and the material is no longer considered reactive.[46] The only gaseous emission is NO_x which is controlled using a wet scrubber and a proprietary ActoHAX reagent.[49]

6.7 MuniRem

The MuniRem process is another solution-based process that uses a sulfur-based reducing agent to reduce the oxidized nitrate-based energetic materials. The MuniRem reagent dithionite, $S_2O_4^{-2}$, strong-base (potassium carbonate etc), and other sulfur-based reducing reagents such as FeS and H_2S are mixed with the shredded energetic in water and allowed to react to form monosaccharides (fructose and glucose).[50] A schematic of the MuniRem process is shown in Figure 15. For nitrocellulose propellants and explosives with plasticizers, the process requires a co-solvent such as dimethyl sulfoxide, acetone, dioxane, or alcohols that can be recovered by evaporation from the process effluent. The process effluent is approved for transfer to a waste water treatment plant, although sludges of metal sulfides and debris would be taken to a normal landfill.

[48] Walia, Daman (2015) Actomil: Proven and Effective Green Sustainable M6 Disposal for Camp Minden, Presented to the EPA Dialog Committee, 4 March 2015

[49] Arctech, (2015) Response to Questions from the EPA Dialog Group Camp Minden, 6 March 2015

[50] Nzengung, V. (2015) Deploying Munirem Technologies to Neutralize Nitrocellulose Propellants and other Explosives, Presentation to the Camp Minden Technology Evaluation Committee, 4 March 2015

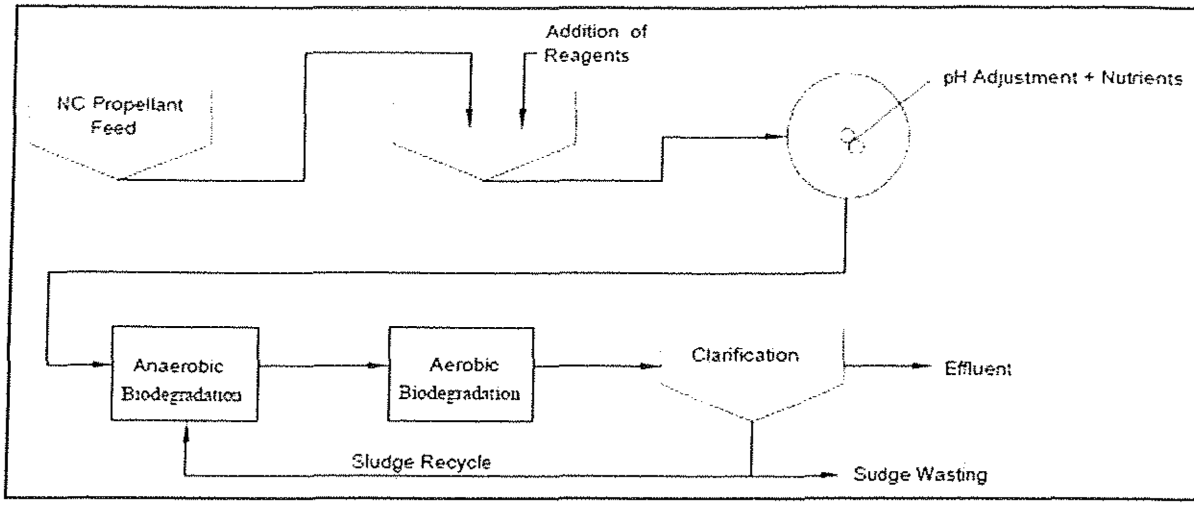

Figure 15. Schematic of the MuniRem Nitrocellulose Destruction Process with Biodegradation [50]

6.8 Rotary Kiln

Rotary kilns are an industry standard for the disposal of waste hazardous materials throughout the developed world. They are currently used in the commercial destruction of explosives such as at the EBV Explosives Environmental Company in Joplin, Missouri, the Veolia Trade Winds facility in Sauget, Illinois, and the EST Energetics GmbH in Rothernburg, Germany. The US Army has long used the APE-1236 deactivation furnace for the destruction of explosives and small arms ammunition. The APE-1236M2 is considered a Maximum Achievable Control Technology (MACT) unit permitted under RCRA and Title 5 of the Clean Air Act (CAA).[51] The APE-1236 deactivation furnace is a 20-ft long and 30.5-inch diameter steel rotary kiln. The kiln is composed of four 5-foot sections bolted together with the two center sections having wall thickness of 3.25 inches and the two end sections having a wall thickness of 2.25 inches. The temperatures in the furnace range from 177°C–260°C at the feed end to 800°C–1100°C at the discharge end. The furnace operates under a negative pressure of 0.15–0.25 inches of water. The furnace is generally limited to 238 NEW lbs/hour. The explosives and ammunition are pushed through the furnace by means of spiral flights which provide physical separation of groups and prevents sympathetic detonations. The rotary furnace is surrounded by a barrier wall for personnel safety. The APE 1236M2 deactivation furnace was designed by the U.S. Army to destroy obsolete or unserviceable ammunition ranging from small arms through 20-mm rounds. Ammunition larger than 20-mm must be sectioned or disassembled prior to being fed to the unit. A schematic of the APE-1236 deactivation furnace and associated pollution abatement system is shown in Figure 16. The rotary kiln is equipped with a No. 2 fuel oil burner that is used to pre-heat and maintain the combustion chamber temperature for ignition and incineration of the waste munitions. A combustion air fan provides oxygen for combustion of the fuel and waste streams. Ash and metal components that are not entrained in the flue gases are discharged at the burner end of the kiln onto a discharge conveyor. The discharge conveyor moves the remaining material to an adjacent accumulation area for subsequent removal.

From the kiln, the flue gas is transported to the cyclone to ensure that no sparks are conveyed to downstream equipment. After the cyclone, the flue gas enters the afterburner equipped with a No. 2 fuel oil burner to further heat the combustion gases and destroy any remaining organics. Propane is used during the burner ignition sequence to ignite the afterburner. Following the afterburner, the flue gases pass through stainless

[51] Oklahoma Department of Environmental Quality (2006) Permit 2005-301, McAlester Army Ammunition Plant (MCAAP) Munitions Deactivation Furnace

steel ductwork to the high temperature ceramic baghouse. An induced draft fan pulls the flue gases through the incineration system before discharge through the exhaust stack.

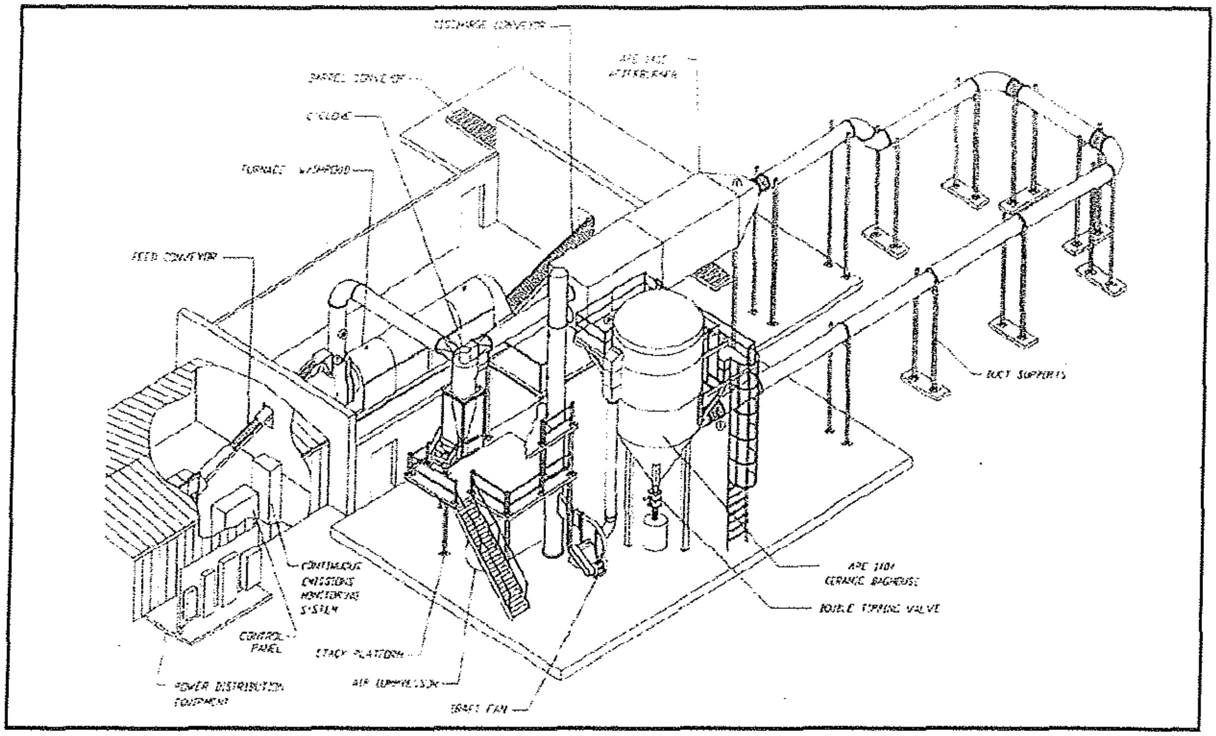

Figure 16. APE–1236 Deactivation Furnace and Pollution Abatement System [52]

Some plants have a Munitions Cryofracture Demilitarization Facility (MCDF) that disassembles the larger munitions prior to feeding them to the rotary kiln. The cryofracture process freezes, fractures, punches, and exposes the energetic material prior to delivering it to the incineration system. Waste munitions can be fed from either an Automatic Waste Feed Conveyor that delivers ammunition smaller than 20-mm or a Positive Feed system (PFS) that delivers cryofractured waste from the MCDF. The system is configured so that only one of the delivery systems can operate at any given time.

Recently, the U.S. Army reviewed the operational history of the APE-1236 and conducted studies to improve reliability and efficiency.[52] This evaluation occurred due to low operational availability (48– 54%), high repair times, safety system weaknesses, and variable and low feed-rates of propellant, explosive and pyrotechnics (PEP) at various sites. The study recommended a redesigned feed system and controls, upgrade of the discharge conveyor to reduce accumulation of material and stoppages, installation of more efficient burners to optimize efficiency and provide better temperature control, replacement of the ceramic baghouse with an evaporative cooler/fabric filter baghouse to improve maintainability and reduce dioxin/furan emissions, and adding additional retorts with greater wall thickness (4 inches) to increase PEP processing rates and provide a longer residence time.

Rotary kiln technology is also in use at the only other commercial explosive waste facility in the U.S. that processes mainly military explosives and munitions, EBV Explosives Environmental Company (EBVEEC), Joplin, Missouri. EBVEEC uses a 3-1/4-inch thick cast steel rotary kiln in addition to a car bottom furnace for explosive contaminated rags, PPE, and packaging, and to flash contaminated metal parts. Veolia ES Technical Solutions, Sauget, Illinois, the only other commercial hazardous waste facility in the

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[52] Sullivan, F. (2015) A Productivity Improvement Study of the APE-1236M2 Rotary Kiln Incinerator, Presentation at the 2015 Global Demilitarization Symposium, Parsippany New Jersey

U.S. treating explosive materials other than the CHC facility also has a rotary kiln and two fixed hearth furnaces. The EST Energetics plant in Rothenburg, Germany, has a 40 mm steel-lined rotary kiln in addition to a refractory-lined rotary kiln.

6.9 Decineration

Decineration is a thermal treatment process patented (US2012/0259149 A1) by U.S. Demil in which explosive materials are exposed to temperatures below the combustion temperature of the explosive to partially decompose the long chain organics in the energetics resulting in nonexplosive organic vapors that are subsequently destroyed in a secondary combustor (afterburner or catalytic converter or thermal oxidizer). The heating takes place in an electrically-heated rotary kiln at approximately 450°F (232°C) and avoids detonation and generation of volatile energetic compounds. The rotary kiln is 30-feet long (14.5-feet heated) and 2-feet in diameter. Waste is fed to the furnace through a weight feed monitoring system consisting of an explosion proof scale, a push off box, and a slide chute. The energetic materials are propelled through the kiln by an Archimedes screw attached to the inside of the furnace tube. During heating, the energetic material decomposes and any high order detonations are contained by the cast iron furnace walls. Retention time is controlled by the speed of rotation, and physical separation of the profiles is achieved by the spiral flights. The furnace is surrounded by barrier walls for additional protection. The scrap metal exits the furnace onto the discharge conveyor that passes through the barrier wall and deposits the material into containers for disposal or recycle. The Decineration process was permitted to operate at the Tooele Army Ammunition Depot, however, and used the cyclone, afterburner, ceramic filter baghouse, and stack of the existing APE-1236 pollution abatement system with the associated monitoring instrumentation. The pollution abatements system establishes a negative pressure of 0.15–0.25 in H_2O in the rotary kiln. U.S. Demil proposes to use a wet scrubber and catalytic converter in place of the afterburner and baghouse. Some of the articles, such as mines, required preparation by cyrofracture prior to being fed into the Decineration system. At Tooele, the unit was permitted to burn up to 150 lbs/hr of propellant, energetics, and pyrotechnics (PEP) and a gross weight of less than 550 lbs/hr for ten hours per day.

6.10 Tunnel Furnace

A tunnel furnace is similar to a rotary kiln in that the material is fed through an airlock in one end of the furnace and slowly moves through the combustion chamber and the residue is dumped. To feed a tunnel furnace, the energetics are loaded into individual trays that carry the material through the combustion chamber rather than through the rotation of the spiral lifts in the rotary kiln. Emissions generated in the enclosed combustion chamber are captured and treated in a pollution abatement system with a Thermal Oxidizer to assure total combustion of organic vapors.[53] Maximum capacities have demonstrated 120 kg/hr, however, CH2MHill stated they could custom design a plant for 1200 kg/hr for M-6 and CBI.[54]

7. ENVIRONMENTAL PROTECTION

As noted above, the principal disadvantage of OBOD as an energetics disposal technology is the lack of systems to control the release of combustion byproducts, volatile metals, and smoke generated during the destruction process, even though, as discussed in Section 6.1, the emissions may be estimated to cause little adverse environmental or human health impacts. As shown at RFAAP and Camp Minden, the lack of these controls and the obvious visual evidence of smoke plumes can stimulate significant public and regulatory concerns. Therefore, any alternative destruction technology proposed to replace OBOD must meet the RCRA Part B Subpart X emission limits or the maximum achievable control technology (MACT) appropriate for that technology.[55] Any energetics incinerator or thermal treatment system will require a

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[53] CH2M Hill, (2015) Responses to questions from the EPA Dialog Group Camp Minden

[54] CH2M Hill (2015) Camp Minden M6 and CBI Potential Technology Screen Information

[55] 40 CFR part 264 (2012) Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities

pollution abatement system that controls the emissions of uncombusted organics, particulates, volatile metals, dioxin/furans, and NO_x. Most systems will incorporate an afterburner or Thermal Oxidizer to control organics, a cyclone and baghouse for particulates, Selective Nitrogen Reduction Control system for NOx, and in some cases HEPA and/or activated carbon filters. A continuous monitoring system for carbon monoxide (CO) and percent oxygen will be required along with the appropriate sampling system to pull a gas sample from the stack. Systems using hydrolysis or liquid based oxidation system will require the appropriate process to control volatile organics, liquid aerosols and other gases emission such as NO_x. The emission standards for new hazardous waste incinerators are shown in Table 19.

Table 19. Emission Standards for New Hazardous Waste Incinerators [55]

Constituent of Concern	Emission Limit corrected to 7% Oxygen
Destruction and Removal Efficiency (DRE)	99.99%
Dioxins and Furans	0.11 ng TEQ/dscm or 0.20 if < 400 °C at PCS
Mercury	8.1 ug/dscm
Cadmium, Lead and Selenium combined	10 ug/dscm
Antimony, Arsenic, Beryllium, Chromium Cobalt, manganese and Nickel combined	10 ug/dscm
Carbon Monoxide	100 ppmv
Total Hydrocarbons	10 ppm on a 10 hour rolling average
Hydrogen chloride and Chlorine as (Cl^-)	21 ppmv
Particulate Matter	0.0016 gr.dscf

TEQ – Toxicity equivalent concentration, ng – nanogram, ug - microgram, dscm – dry standard cubic meter, ppmv – part per million by volume, gr – grains, dscf – dry standard cubic foot, PAS – Particulate control system

The system must also be designed and practices put into place to treat and prevent release of hazardous aqueous waste derived from preparation activities such as size reduction or caustic solutions used in hydrolysis destruction processes. Since the Colfax facility lacks industrial or domestic sewer connections, there must be accommodations for collection and transport to appropriate offsite permitted treatment and disposal facilities. Routine monitoring of the soil and water surrounding the disposal facility must demonstrate there are no adverse environmental impacts or harm to the local public.

8. EVALUATING ALTERNATIVE TECHNOLOGIES

8.1 Evaluation Criteria

The evaluation criteria used by previous assessments of EM destruction technology whether for chemical munitions or alternatives to OBOD have been similar. They include process safety, process robustness, throughput, environmental protection, secondary waste, industrial experience, and public acceptance.[12, 13]

[56, 57] Cost was not evaluated since the vendors would have required a detailed specification to provide an accurate cost estimate.

8.2 Process Safety

Safety for workers and the public is a primary consideration in the selection and siting of an EM disposal facility. Demonstration of a solid history of operations without a serious incident or accident will be an important evaluation factor. While the Colfax facility is located in a remote location with few private residences, other commercial buildings, or highly traveled roads, safety of all operations from EM waste delivery, transport on site, handling storage, preparation, destruction, and waste treatment must be inherently safe. As noted in Section 5. 1, the more on-site transport, handling, and preparation required prior to actual destruction, the more workers are exposed to increased risk. The optimal system would be able to accept and effectively destroy a broad range of EM with minimal handling, disassembly or size reduction. Due to the diverse waste stream accepted at the Colfax facility it is unrealistic to expect no prior preparation before destruction, but the more robust the process in its ability to process the waste stream without excess handling makes it more inherently safe.

Approval of the technology by the DDESB provides assurances that the explosive safety aspects of the system have been systematically reviewed in accordance with DoDI 6055.16.[58] The DDESB only reviews systems to be used in DoD operations but has provided input on alternative technologies for assessments to replace OBOD at RFAAP and Camp Minden.

The system must have reliable engineering controls that provide real-time feedback of the process conditions, and facilitate instantaneous response to process upset and automatic waste feed cut-off. The system design must incorporate blast barriers and other isolation measures to assure accidental and/or unintentional detonations or burns are contained and personnel are protected from blast, fragments, or thermal effects.

8.3 Process Robustness

One of the most important selection criterions after safety is the robustness of the system for handling the waste stream of a waste disposal facility. Many of the explosive destruction systems have been designed for facilities that are processing a particular propellant such as at Camp Minden or demilitarization of a specific mix of munitions such as found at a chemical demilitarization site or ammunition depot. In these cases, the waste stream is well defined, large quantities can be processed at one time, and the destruction process can be tuned to give an optimum DRE. A waste disposal facility has a much broader spectrum of wastes; therefore, the disposal system must be flexible enough to handle the broad range of permitted profiles routinely with minimal specialized pretreatment to be efficient and to minimize personnel exposure.

As described in Section 3.2, the Facility is permitted to thermally treat 561,700 lbs (net explosive weight) per year. The facility processed over 210 categories of materials including bulk explosives, solid propellants, detonators, fireworks, small ammunitions, signal flares, shaped charges, rocket motors, detonating cord and black powder. A large percentage of the total weight processed (50%) comes from just three categories: Substances Explosive N.O.S. 1.1D, 1.3C, and solid propellant 1.3C. In 2016, the most recent reporting year, slightly over 53% of the material disposed of was in four categories: Substances explosive N.O.S. 1.1D, 1.3C, 1.4C, and solid propellant 1.3C.

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[56] National Research Council (2006) review of International Technologies for Destruction of Recovered Chemical Warfare Munitions, National Academies Press

[57] Camp Minden Evaluation Committee (2015) Preliminary Compilation of Possible Alternative Remedies Document 9545941

[58] Department of Defense Instruction (2011) Explosive Safety Management Program, DoDI 6055.16, with Change 1 December 8, 2011

The technology vendors were provided the following categories to assess the robustness of the system and evaluate the preprocessing access/disassembly/size reduction preparation required to process the waste profiles.

a. Substances, explosives N.O.S. (UN0473)
b. Bulk explosives (UN0475)
c. Solid Propellants (UN0499)
d. Liquid Propellants (UN0495)
e. Detonation cord (UN0065)
f. Pyrotechnics (UN0333)
g. Shaped Charges w/o detonators(UN0440)
h. Boosters without detonators (UN0042)
i. Cylinders pyrophoric gases (UN0380)
j. Flares aerial (UN0093)
k. Cartridges (UN0339) State maximum size
l. Grenades, smoke (UN0016)
m. Compressed gas, Toxic, Flammable N.O.S. (UN 1953)
n. Ammunition fixed (UN 0006) (Please provide maximum size round accommodated)

8.4 Throughput

The Colfax facility is currently permitted to thermally treat 561,700 lbs (net explosive weight-NEW) per year and up to 410 lbs NEW per hour. The alternative to OBOD needs to be capable of acquiring a permit from the Louisiana Department of Environmental Quality to safely dispose of propellants, explosives, and pyrotechnics at this feed rate while achieving a DRE of 99.99% and meeting permitted emissions limits. Capacity will be assessed for bulk propellants and explosives, cartridges and pyrotechnics.

8.5 Environmental Protection

All emissions (liquid, solids and gaseous) must be controlled to protect the workers, public and the environment. The pollution abatement system must incorporate proven technology to assure all emissions are within LDEQ permit limits or EPA MACT standards. The technology must be reliable, low maintenance, and with a reasonable operational cost.

8.6 Secondary Waste

The destruction process and pollution abatement system should generate minimal secondary waste that requires no additional treatment other than solidification and can be disposed of off-site at permitted landfills. Due to the remote location and lack of access to either a domestic or industrial sewer system, liquid waste will require off-site transport and disposal and so should be minimized.

8.7 Industrial Experience

Commercial/government operational experience is important to evaluate reliability, operational availability, safety, maintenance, and operation costs. *Demonstrated experience with a diverse waste stream and compliance with environmental regulation will be given substantial weight due to the importance of efficient operation in a commercial waste disposal operation.*

8.8 Public Acceptance

Public acceptance is a subjective criterion; however, it is a factor that should be considered due to the heightened sensitivity to explosive disposal in Louisiana resulting from the public involvement in the selection of the technology to dispose of the M-6 and clean burning igniters at Camp Minden. The community dialog group had nine criteria, most of which are consistent with the above evaluation factors, but in addition, listed community acceptance. This included acceptance by the community leaders, affected community, response community, and on-site workers. While there were no specific factors provided for public acceptance, in the correspondence to the EPA, presentations to the dialog committee, and in comments by committee members it was evident there was strong consensus that OBOD was unacceptable. Overall, the proposed technologies were fairly evaluated by the committee without a bias for or against a certain type of process. Some members of the community pushed solution-based technologies such as SCWO, because of their false impression that these processes did not have air emissions as compared to incineration or other thermal destruction system. All alternatives will require pollution control systems to meet the state of Louisiana Department of Environmental Quality permit requirements.

9. TECHNOLOGY ASSESSMENT

Each of the alternatives to OBOD has advantages and disadvantages depending on the characteristics of the waste stream that the facility receives. For a facility such as CHC, accepting waste energetics from across the country, it is critical that the destruction technology be able to handle the over 210 categories of energetic materials safely and efficiently while protecting the workers, public, and the environment. The relative merits of the various destruction technologies would be very different for a facility treating a defined homogeneous waste stream dominated by contaminated bulk explosives and propellants. In particular, processes where the handling, preparation, and process chemistry need to be tailored to the particular energetic or configuration are at a disadvantage handling a broad spectrum of energetic wastes. These technologies require much more segregation, handling and mechanical access than do more robust technologies such as rotary kilns or contained burn/detonation chambers. While a significant portion of the manifested EM is bulk explosives and propellants (single- and double-base), there are many other munitions, rocket motors, bursters, ammunition, fireworks, detonating cord, and other devices that must be efficiently and effectively destroyed in a way that is protective of the workers, public, and environment. Table 22, below, provides a relative assessment of the most common technologies for destroying the waste stream at the Colfax facility.

Table 20. Relative Assessment of Potential Technologies to OBOD for Disposal of Energetic Materials at the Colfax Facility

Criteria	OBOD	Armored Rotary Kiln	Refractory -ined Rotary Kiln	Decineration	Contained Burn	Static Kiln	Oxidation/Reduction Processes	Hydrolysis	SCWO
Safety	0	0	0	0	0	0	0	0	0
Robustness	0	+	-	-	-	+	--	--	--
Throughput	0	0	0	0	0	0	-	-	-
Environmental	0	+	+	+	+	+	+	+	+
Secondary Waste	0	0	0	0	0	0	-	-	-
Industrial Experience	0	++	++	--	++	++	--	--	--
Utilities	0	--	--	-	-	--	0	0	-
Public Acceptance	0	+	+	++	+	+	++	++	++
Overall	0	1	-1	-2	0	1	-4	-4	-5

In reviewing the various alternative technologies, the principle factors used to evaluate applicability for the Colfax facility were safety, robustness, throughput, environmental protection, secondary waste generation, industrial experience, utilities, and public acceptance. Many of the technologies reviewed in this and previous assessments are still in early development or have been used on a very narrow range of energetics and, therefore, were not deemed mature or robust enough for a commercial operation. After evaluating the alternatives against the above criteria, the systems with the highest rating as potential replacement for OBOD are the armored rotary kiln and static kiln. This is primarily a function of their robustness to be able to handle any energetic with minimal preparation and extensive industrial experience. The contained burn and refractory-lined rotary kiln are other alternatives but cannot contain detonations so all munitions would have to be prepared to avoid any high energy events. The tradeoff between the systems that can process detonable energetics and container burn may be in the relative capital costs and operational manpower required. The solution-based technologies including SCWO are all rated low due to their need for extensive processing to guarantee access to the energetic and lack of any industrial experience. Their main positive attribute is the public's perception that there is less environmental risk with non-thermal technologies. Decineration is an immature concept that shows promise due to potential energy savings, but experience with this technology is limited to a partial system demonstration with a limited feed stream.

10. REQUEST FOR INFORMATION (RFI) EVALUATIONS

A request for information was sent to twelve vendors of EM destruction technology. The companies were selected from those reviewed in other alternative technology evaluations and reputations in the energetics disposal industry. Of the twelve vendors, only six provided information, even though they were contacted repeatedly. Fortunately, the responders were from a cross section of the technologies originally identified including solution-based chemistries, thermal destruction, and super critical oxidation (SCWO). Each of these responses and their proposed technologies is evaluated below.

10.1 MuniRem™

The MuniRem technology uses alkaline hydrolysis with a hydrothionite reducing agent ($Na_2S_2O_4$, H_2S, FeS) in batch reactors to treat *explosives.*

10.1.1 Process Safety

The primary safety hazard is the preparation required to access the explosive through shredding, cryogenics, water jet or other mechanical sizing techniques. Handling caustics and the potential for formation of the hazardous gas - hydrogen sulfide (H_2S) - could be work place safety concerns. Organic co-solvents (dimethyl sulfoxide, acetone, dioxane, alcohols) required for plasticized propellants could pose flammability and/or toxicity hazards.

10.1.2 Robustness

The MuniRem process has generally been used to decontaminate soil, buildings, equipment and munition casings. It was also used to destroy almost 2000 pounds of bulk H-6 (nitrocellulose), H-6 contaminated sediments recovered from old production equipment. It has not been used to process large quantities of bulk explosives, munitions, or pyrophorics. The process would be similar to hydrolysis for bulk explosives or propellants. Propellants with plasticizer would require an appropriate organic co-solvent that would need to be evaporated and recovered prior to disposal. Perchlorate based propellants or pyrophorics would require a separate biodegradation process. The processing would require experience to segregate by explosive type, to assure complete destruction of all energetics and to confirm the waste water meets all discharge criteria for transport to a wastewater treatment plant (WWTP). Depending on the WWTP, biodegradation and denitrification of the waste water may be required prior to disposal. All munitions and ammunition would require preparation to access the alkaline solution by cutting, cryogenic crushing, or shredding prior to treatment.

10.1.3 Throughput

The vendor states the process is scalable and 200 lbs/hr NEW bulk explosives, 2200 lbs/hr cartridges, and 500 lbs/hr pyrotechnics is achievable.

10.1.4 Environmental Protection

Since this is a wet process, the vendor asserts there is no pollution abatement required. This may come under question since the experience showed that there were gaseous emissions from the alkaline hydrolysis treatment system. Further investigation is required to determine if this process would meet emissions regulations.

10.1.5 Secondary Waste

The major waste product will be the spent solutions with the residual organics (formates, acetates) and inorganics (nitrites, sulfides, thiosulfates and sulfites). The process is designed to recycle water; however, at some point, discharge to the WWTP will be required. There also will be sludges and metal debris for disposal in landfills.

10.1.6 Industrial Experience and Maturity of Technology

Almost all the experience has been in small projects for soil remediation, building and equipment decontamination and the destruction of residual explosives on munitions from which the explosives have been removed by melting or some other process. Approximately 2000 pounds of H-6t propellant and contaminated sludge and sediment was treated at Camp Minden from old processing equipment.

10.1.7 Public Acceptance

As a non-thermal destruction system, experience has shown from other alternative technology forums that the MuniRem process will have great public acceptance. There is a strong perception among some members of the public that solution-based systems are safer and do not emit pollutants.

10.1.8 Utilities

No unusual utilities are required. Water will be the primary input other than the proprietary MuniRem reagents. Electricity for pumps, controls and heaters should be standard 120V or 220 V. Liquid effluent will have to be transported by tanker truck to an offsite WWTP.

10.1.9 Summary

The MuniRem process appears to have merit for soil remediation and decontamination of buildings and equipment. There is no industrial size experience with large quantities of diverse energetics and pyrophorics. As with other solution-based technologies, the munitions and pyrophorics would require preparation to provide access and size reduction. The process appears to effectively destroy standard explosives and propellants; however, propellants with plasticizer would require an organic co-solvent and an evaporation process to recover the solvent. The process would require customization for different energetics and the effluent may need additional biodegradation and denitrification prior to disposal. The process appears safe and there are no unusual costs associated with installation or operation.

10.2 Decineration™

The Decineration process involves the low temperature heating (450°F) of the energetics in an electrical rotary furnace which results in "cracking" of the nitramines and nitrate esters with the loss of volatile low molecular weight organics rather than ignition/oxidation the thermal oxidation. The evolved volatile organics are eventually destroyed in a catalytic thermal oxidizer as part of the pollution abatement system. The low temperature of the Decineration process generates sufficient gas pressure in the ammunition to force the bullet from the casing but is too low to initiate combustion.

10.2.1 Process Safety

During the processing of RDX, an exothermic reaction in the kiln did cause a temperature excursion that exceeded the control system capabilities. Generally, the Decineration process will require some manner of size reduction such as water jet cutting to control the NEW content of the furnace to < 8.5 lbs TNT equivalent and to fit items through the feed inlet. The use of electrical heating and lack of detonations in the furnace are seen as a positive safety features. In a test demonstration at Tooele Ammunition Depot (TEAD), the Decineration system process over 24.5 tons of assembled munitions over 2 months without an accident or incident.

10.2.2 Robustness

The Decineration process is configured to handle bulk explosives, propellants, and liquid propellants. Shaped charges and warheads would require size reduction by water jet cutting. Ammonium perchlorate and ammonium nitrate would not be applicable since they begin to melt and explosively decompose at close to the proposed operating temperature of the Decineration process (250°C). This process would not be effective against commercial fireworks.

10.2.3 Throughput

The current Decineration furnace is rated at 8.5 lbs TNT equivalent which results in a throughput of between 28.3 and 31.7 lbs TNT/hour at the normal dwell times. The vendor states that a rate of 410 lbs/hour is achievable with a new rotary tube design and furnace sizing.

10.2.4 Environmental Protection

The pollution abatement system (PAS) of the Decineration process consists of a wet scrubber and an electrically preheated catalytic thermal oxidizer (700°F) that converts the volatile organics to CO_2. The water from the sludge from the wet scrubber is separated from the scrubber water by a filter press. The thermal oxidizer, once preheated, can generate its own heat due to the combustion of the volatile organics and so the preheater is shut off. An ID fan generates air flow through the system and discharges through a 30-foot high stack with the required continuous emission monitoring system (CEMS)

10.2.5 Secondary Waste

The Decineration process would only generate metal debris and dry cake from the wet scrubber, both of which the vendor states can be sold as metal scrap.

10.2.6 Industrial Experience and Maturity of Technology

The Decineration system has only been operated at Tooele Ammunition Depot (TEAD) in a side-to-side comparison with the APE 1236 Rotary kiln. Only the Decineration furnace was operated as the two systems used the same APE 1236 PAS. The furnace processed a total of 24.5 tons of various assembled munitions over a two-month period. There is proposed installation at Crane Army Ammunition Activity (CAAA) to process Cartridge Actuated Devices (CADs), Propellant Actuated Devices (PADs) and Small Arms Ammunition (SAA).

10.2.7 Public Acceptance

Although this is a thermal system, the low temperature reduces the potential for dioxins/furans if there is chlorine present in the waste. This is an often expressed concern at public hearings. The process would still be viewed as thermal destruction, although the argument would be made by the vendor that it is not combustion. The Title V permitting process would be similar to that for a rotary kiln and the emission would be held to the same limits. The claim that this is not an incinerator (as agreed to in the EPA Office of Solid Waste letter) but a metal recycling operation would be appropriate for the CHC facility.

10.2.8 Utilities

The Decineration system operates only with electricity (116 kW/hr for the TEAD unit) and some make-up water for the wet scrubber. This eliminates the need for natural gas or fuel oil.

10.2.9 Summary

The system proposed for the Decineration process appears to be similar to a rotary kiln with the following differences. It is low temperature, minimizing the opportunity for deflagrations in the rotating tube and reduces the potential for dioxin/furan formation if there is chlorine present. Size reduction would still be required to control the feed rate to the maximum NEW limit and handle shaped charges and warheads. The process may be limited in processing ammonium nitrate and ammonium perchlorate since these explosives and propellants do not off gas volatile organics and can violently decompose close to operating temperatures of the Decineration furnace. With only electricity required, the provision of utilities is simplified. The proposed PAS with a state-of-the-art CEMS should not pose any permitting issue.

10.3 Eisenmann

Eisenmann is a large family-owned international company from Böblingen, Germany, with core competence in incineration of solid, liquid and gaseous wastes that has installed numerous energetic material (EM) destruction facilities across Europe and Asia. Their response to the request for information (RFI) was mostly generic with specific examples of the technology most appropriate for each type of energetic waste. For bulk propellants and non-deflagration/detonation explosives, they suggest a refractory lined rotary kiln and for those explosives such as RDX, pyrotechnics, detonation cord, disassembled shaped charges, flares, ammunition, grenades and boosters without detonators, they recommend an armored full-steel rotary kiln. The refractory-lined kiln can operate at higher temperatures than the steel-lined providing enhanced throughput, however, cannot handle detonations. Eisenmann recommends a separate technology for processing liquids and compressed gas cylinders (TURAKTOR).

10.3.1 Process Safety

Eisenmann states that no incidents or accidents have occurred in their multiple ammunition disposal plants in Europe and Asia.

10.3.2 Robustness

All the wastes identified in the RFI were capable of being destroyed with the steel-lined rotary kiln including pyrophoric and toxic gases. Preparation of certain EM will require size reduction and/or disassembly.

10.3.3 Throughput

Eisenmann states that they can custom design to throughput rates of up to 1000 kg/hr NEW of bulk explosives, 200 kg/hr of cartridges, and 250 kg/hr for pyrotechnics.

10.3.4 Environmental Protection

The flue gas cleaning system is designed to the specific EM and regulatory emission limits and can be wet, semi-dry, or dry. Most systems composed of a post combustion chamber, quench, wet scrubber stack and continuous monitoring systems.

10.3.5 Secondary Waste

Generally, the secondary waste from a rotary kiln is composed of fly ash and metals and liquid wastes and sludge from a wet flue gas treatment system.

10.3.6 Industrial Experience and Maturity of Technology

Eisenmann is probably one of the largest international companies producing EM, ammunition, and chemical weapons disposal systems. They have installed plants in Europe, Russia, China, Albania, USA, Mexico and South America. Rotary kiln technology is the industry standard for EM destruction facilities.

10.3.7 Public Acceptance

There has been a significant public pushback against incineration despite its long history of safe and effective operations destroying hazardous and energetic wastes. The international reputation, solid operational experience, and impeccable safety record may sway those in the public that are willing to objectively assess the technical performance of the system.

10.3.8 Utilities

The rotary kiln system and afterburner can both operate on natural gas. The only other utilities are electricity and make-up water for the PAS quench.

10.3.9 Summary

While the Eisenmann response was generic, their rotary kiln system and PAS system appear to be a robust proven technology with the capability to more than handle the Colfax waste stream. Their extensive operational history at multiple facilities with a demonstrated safety record is impressive.

10.4 Continental Research and Engineering

The Continental Research and Engineering (CR&E) approach uses a proven rotary kiln technology that has been used at six facilities in the U.S. demilitarization program for over 2 decades. The deactivation furnace system (DFS) was used to destroy the explosive components of chemical weapons. CR&E has modified the basic design to meet the requirements of the Colfax facility.

10.4.1 Process Safety

The DFS has been operated at six demilitarization facilities and has processed over 3800 tons of propellants and 2100 tons of explosives, during which there were only two incidents involving the DFS. One was a small chemical agent leak caused by operator error during start up with a cold furnace and the other was the result of a broken bolt in the afterburner by a poorly designed refractory. The afterburner was redesigned to provide sufficient refractory expansion in the vessel. CR&E proposed to use commercial water jet cutting with an indexing conveyor for size reduction.

10.4.2 Robustness

All the wastes identified in the RFI are capable of being destroyed with the steel-lined rotary kiln including pyrophoric and toxic gases. Preparation of certain EM will require size reduction and/or disassembly. The thermal treatment unit design also accommodates injection of waste water jet cutting fluids, liquid energetics, and toxic compressed gases.

10.4.3 Throughput

The CR&E rotary kiln design provides for feeding bulk explosives and propellants (1200 lbs/hr), cartridges (900 lbs/hr), and pyrotechnics (900 lbs/hr).

10.4.4 Environmental Protection

The pollution abatement system (PAS) consists of a natural gas-fueled afterburner to destroy unburned hydrocarbons, quench tower, venture scrubber, packed bed scrubber, clean liquor air cooler, and mist eliminator. A continuous environmental monitoring system (CEMS) for CO, CO_2 and O_2 will be installed between the induced–draft fan and stack. If the CEMS detects emissions above the control limits, it causes an automatic waste feed cut off (AWFCO).

10.4.5 Secondary Waste

The secondary waste stream will consist of fly ash and metals from casing and other metallic components. There will also be a caustic liquid waste stream from the PAS containing aluminum, salts, and fly ash.

10.4.6 Industrial Experience and Maturity of Technology

The rotary kiln design proposed by CR&E has a proven track record of over 25 years in operation destroying energetics in the demilitarization program. Rotary kiln technology is the industry standard for EM destruction facilities.

10.4.7 Public Acceptance

There has been a significant public pushback against incineration despite its long history of safe and effective operations destroying hazardous and energetic wastes. The solid operational experience and impeccable safety record for 20 years may sway those in the public that are willing to objectively assess the technical performance of the system.

10.4.8 Utilities

The rotary kiln system and afterburner both operate on natural gas. The only other utilities are electricity (1000 KW) and make-up water for the PAS quench.

10.4.9 Summary

The CR&E rotary kiln system and PAS appear to be a robust proven technology with the capability to more than handle the Colfax waste stream. The system has a strong operational history and safety record at multiple facilities.

10.5 El Dorado Engineering Inc.

El Dorado Engineering Inc. (EDE) has been an international leader in the design and construction of closed thermal treatment systems for explosive wastes for over 35 years. They have designed and built explosive waste incinerators, transportable flash furnaces, contained burn systems, energetics recovery systems, and made significant contributions to the U.S. and Russian chemical agent stockpile demilitarization programs. EDE proposed two solutions for the Colfax waste stream: a rotary kiln explosive waste incinerator and a contained burn system.

10.5.1 Process Safety

EDE states full process safety hazards analyses (PSHAs) and destructive testing have been accomplished to verify the NEW limits. They also confirm there have been no accidents with any of their systems. The rotary kiln and contained burn have extensive operational histories in both the commercial explosive waste destruction and military munitions demilitarization environments. The EDE contained burn system at Camp Minden has completed destruction of over 12 million pounds of propellant in nine months and is on track to complete emergency destruction of the full 15 million pounds in less than a year.

10.5.2 Robustness

The steel rotary kiln is the most robust technology for waste explosive destruction. The rotary kiln handles bulk explosives (single-base, double-base, triple-base, and composites propellants), small caliber ammunition up to and including 30 mm rounds, large artillery rounds, flares, fuses , primers, booster, and prepared projectiles. The only items that would require a special feed system are the compressed gases. The contained burn system can accommodate most articles without special handling except those deflagrate rapidly or mass high order detonations. Items, like small arms ammunition, that might create fragments must be fed in through a strongbox. Compressed gas would also need a special feed system.

10.5.3 Throughput

The EDE rotary kiln is designed for a bulk explosive or propellant feed rate of 50–150 kg/hr depending on the configuration. The feed rate for small arms is up to approximately 550 kg/hr. The contained burn has a wide range of design capacities from 5 to over 1200 kg/hr with the largest system handling batch sizes of 400 kg with three burn cycles/hr.

10.5.4 Environmental Protection

The rotary kiln incinerator would be permitted as hazardous waste incinerators and would require pollution abatement system that meets the RCRA MACT EEE regulation. The EDE air pollution control system would include an afterburner, cyclone particle separator, gas cooling system, high efficiency filter bag house, an induced-draft fan, and stack. A dry scrubber for acid gas control and a continuous emission monitoring system can be added as options. The contained burn systems are regulated under RCRA Part B subpart X miscellaneous treatment units, the same as OBOD. The pollution abatement system can be tailored but generally consist of gas cooler, a cyclone for particulate removal, baghouse, ID fan and stack. An afterburner and nitrogen oxide removal can be added as an option to assure complete combustion of volatile and semivolatile organics.

10.5.5 Secondary Waste

Secondary waste for the rotary kiln treatment and contained burn systems will consist of ash, metals and other noncombustible materials. The PASs only discharges solid particulates with no liquid waste stream. All wastes are considered hazardous unless proven otherwise by TCLP analytical analysis.

10.5.6 Industrial Experience and Maturity of Technology

For over 35 years, EDE have built numerous explosive waste destruction systems around the world, the most recent ones being a rotary kiln waste explosive incinerator in Belgium and the contained burn system at Camp Minden, Louisiana. The rotary kiln technology is the workhorse of waste explosive destruction and contained burn is a proven technology for disposal of both commercial and military non-detonable energetic waste.

10.5.7 Public Acceptance

Both the rotary kiln and contained burn are thermal treatment systems which are sometimes viewed negatively by some environmental advocates. These systems both incorporate the required pollution abatement systems to assure any emission meet or exceed environmental regulations and permit requirements. Both have proven performance records and the success of the contained burn system at Camp Minden in destroying the waste propellant would enhance public confidence.

10.5.8 Utilities

The rotary kiln system and afterburner can both operate on natural gas. The only other utility would be electricity. The contained burn would only require electricity.

10.5.9 Summary

El Dorado Engineering Inc. is a solid company with years of experience in the design, fabrication and installation of waste explosive destruction systems that have operated safely. The two proposed technologies are standard in the industry and can accommodate the Colfax waste stream with the exception that the compressed gas cylinders would require special feed system.

10.6 General Atomics

The General Atomics industrialized supercritical water oxidation (iSCWO) process destroys liquid wastes at high temperatures (650 °C to 700 °C) and high pressures (3,200 psig). The system consists of high pressure pumps, a reactor, preheater, pressure letdown system, gas-liquid separator, and storage tanks. For the iSCWO the vendor states no pollution abatement system is required, however, as noted below the iSCWO can only treat liquids and liquid slurries, therefore any other solids that are generated with residual energetics will require other treatment including thermal that will require conventional gas pollution treatment systems.

10.6.1 Process Safety

The iSCWO only treats waste in a liquid form so that requires all energetics to be introduced either in solution or in a slurry. All metals have to be separated and treated using some other thermal or hydrolytic process. The vendor General Atomics touts their cryofracture technology which introduces the munitions into a liquid nitrogen bath and after they are stable places them in a hydraulic press where they are crushed. The energetics are separated from the metal debris, mixed with water or caustic and then sent to the iSCWO. The metal debris must be treated using some other treatment system to assure all residual energetics are destroyed. The iSCWO can treat bulk explosives after being reduced in size by grinding and mixed with water. The vendor cites one incident that occurred when engineers were attempting to use liquid oxygen as an oxidant rather than air. They state that they only use compressed air in the system now.

10.6.2 Robustness

The inability of the iSCWO to handle solids would require significant preprocessing to size and separate the energetics from other solid constituents. The cyrofracture process is limited to 5 lbs NEW per cycle of the hydraulic press so any item larger than this must be mechanically cut by water jet or saw. In addition the treatment of these solid wastes would require an additional treatment system along with the associated pollution abatement system. The energetics must be soaked in water or caustic, depending on the type of explosive, prior to grinding for size reduction. This would require separate tanks for water and caustic for soaking and the necessary upfront handling to segregate and perform size reduction.

10.6.3 Pollution Abatement

The vendor states that only CO_2 and N_2 in the gas effluent of the iSCWO and a liquid feed stream with some salt and metal oxides precipitates. Based on the heavy metals such as lead, in some explosives, propellants this liquid waste stream would probably require disposal off-site at a hazardous waste treatment facility. The associated thermal treatment system for processing the solid wastes would require conventional air pollution treatment systems.

10.6.4 Throughput

As noted above the hydraulic press limits the throughput of the cryofracture size reduction system to 5 lbs NEW/minute. The actual NEW limitation for the iSCWO has not been determined as yet; however, the vendor estimates 5 lbs NEW/minute based on a 20% slurry feed.

10.6.5 Secondary Waste

The overall iSCWO process will generate metal precipitates from the thermal treatment system and liquid waste stream with salts and metal precipitates.

10.6.6 Industrial Experience

The only commercial iSCWO unit is operating in France to destroy cleaning solutions used to clean heat exchangers at a nuclear power plant. General Atomics has performed test demonstrations with bulk explosives to determine that they can be mixed with water and ground to produce a slurry. Only energetics previously hydrolyzed in caustic have actually been processed using a SCWO.

10.6.7 Public Acceptance

The public generally likes non-thermal technologies like the iSCWO, however, with the need for a thermal-based solids treatment system that is less likely to be an important advantage. For purely liquid organic wastes energetics the iSCWO would have a decisive advantage in public acceptance.

10.6.8 Utilities

The iSCWO would operate on electricity and would require water to produce the slurries for feeding the energetics. As with the other hydrolysis based system, disposal of the liquid waste would require transport rather than discharge to a sewer system.

10.6.9 Summary

The iSCWO may be a viable destruction technology for liquid organic wastes or, after extensive demonstration testing, bulk energetics. The lack of experience in destroying non-hydrolyzed energetics, no commercial experience, extensive preprocessing (size reduction, cryofracture, generating and transferring solid/liquid slurries), and thermal treatment of solid wastes make iSCWO a poor choice for treating the diverse waste stream at Colfax.

11. CONCLUSIONS

The CHC energetic waste treatment facility is under pressure from local environmental advocates to eliminate OBOD as a treatment option for the 561,700 lbs NEW the facility is permitted to accept for thermal treatment. Nationally, the Colfax facility is the only commercial facility permitted to use OBOD for destruction of energetic materials. The pressure from the local community and environmental advocates is due to general resistance to OBOD of hazardous waste, concerns that the public is being exposed to toxic and hazardous pollutants such as lead and dioxins/furans, and objections to the visible black smoke from the diesel used as an ignition source. The public interest in energetic waste destruction was heightened by previous accidents and the subsequent public participation in the selection of a thermal treatment system for the destruction of over 15 million pounds of propellant at Camp Minden in Northern Louisiana. The Colfax facility also increased public concern by requesting a permit modification to increase their allowed NEW per year from 561,700 lbs NEW/year to 2,055,000 lbs NEW/year for the purpose of treating the waste from Camp Minden. This request was subsequently withdrawn.

The LDEQ permit for the Colfax facility requires quarterly environmental monitoring of the soil, sediments and surface water around the burn pad. In addition, the LDEQ initiated a special soil, groundwater and air monitoring program at the request of the Louisiana legislature. A review of the monitoring data by the Louisiana Department of Health found that the OBOD activities at the CHC facility do not present an immediate and/or substantial threat to human health or the environment.3 Some previous studies have also shown that mass emissions of primary pollutants per day from OBOD are not largely different than those from permitted explosive incinerators.[28]

SwRI conducted an independent assessment of alternative technologies for the management of the waste stream received at the Colfax facility. As part of this assessment, SwRI reviewed previous evaluations of alternatives for other OBOD sites conducted by the DoD, National Research Council, international organizations involved with disposal of unexploded ordnance, and organizations such as the Camp Minden Dialog Group. Each of the evaluations addressed a different environment and waste stream and, therefore, had different criteria for comparing the available alternatives. The primary factor which drove much of the evaluation for Colfax was the diverse waste stream that a commercial treatment facility must handle on a daily basis. Over 210 categories of energetic material come through the facility. This is in contrast to many existing facilities that receive and process bulk propellant, explosive, or standard military munitions. As an example, the Camp Minden selection of the contained burn technology was driven by the homogeneous waste stream of over 15 million pounds of a single propellant M6 and 0.3 million pounds of clean burning igniters.

In reviewing the various alternative technologies, the principle factors used to evaluate applicability for the Colfax facility were safety, robustness, throughput, environmental protection, secondary waste generation, industrial experience, public acceptance, and utilities. Many of the technologies reviewed in this and previous assessments are still in early development or have been used on a very narrow range of energetics and, therefore, were not deemed mature or robust enough for a commercial operation. After evaluating the alternatives against the above criteria, the systems with the highest rating as potential replacement for OBOD were the armored rotary kiln and static kiln. This is primarily a function of the robustness of the systems to handle any energetic with minimal preparation and the extensive industrial experience with this technology. The high rating of armored rotary kiln technology is not unexpected since the other commercial explosive waste facility in the U.S. that processes mainly military explosives and munitions, EBV Explosives Environmental Company, uses a 3-1/4-inch thick cast steel rotary kiln. The EST Energetics plant in Rothenburg, Germany, has a 40 mm steel-lined rotary kiln in addition to a refractory-lined rotary kiln. Three of the vendors who replied to the RFI proposed steel-lined rotary kilns. They all have solid experience with rotary kiln technology. The static kiln is also used worldwide to destroy munitions and explosives, including those contaminated with chemical warfare agents.

The contained burn system also ranked high. The contained furnace is not designed to contain high order detonations so all munitions would have to be prepared to avoid any high energy events. The contained burn is most like the current OBOD except the destruction takes place in a chamber and the emissions are captured and