ELSEVIER Journal of Hazardous Materials B 66 (1999) 279–290

Journal of Hazardous Materials

Surrogate burns in deactivation furnace system

Jay K. Shah *

Science Applications International, 11620 Stark Rd., Tooele, UT, USA

Received 26 August 1998; received in revised form 12 January 1999; accepted 14 January 1999

Abstract

The deactivation furnace system at the Deseret Chemical Depot in Utah is designed for processing explosive components from munitions containing nerve and mustard agents. The system was installed during the period of 1989 through 1993. The Utah Division of Solid and Hazardous Waste (UDSHW) required that trial burns be conducted using surrogate chemicals prior to introducing chemical agents into the system. The selected surrogate chemicals were monochlorobenzene and hexachloroethane based on the criteria established by the UDSHW. Three surrogate runs were conducted in October, 1995. The gaseous emissions and liquid and solid effluents were sampled and analyzed using approved EPA methods. The trial burns demonstrated the desirable destruction and removal efficiency for the selected surrogate chemicals. The pollution abatement system demonstrated the desired scrubbing efficiency for acid gases generated during incineration of chlorinated surrogate chemicals. The particulate removal efficiency during the trial burns was also considerably higher than required by regulations. After comprehensive review of the performance of the deactivation furnace system during the surrogate trial burns, UDSHW approved introduction of GB nerve agent into the system to prepare it for agent trial burns.

Keywords: Deactivation; Explosives; Nerve agent; Mustard agent; Incineration; Surrogate

1. Introduction

The U.S. Army has a stockpile of chemical agents at eight sites within continental USA and also at Johnson Atoll in the Pacific Ocean. About 43% of the stockpile is

* Tel.: +1-435-833-7455; Fax: +1-435-833-7696.

0304-3894/99/$ - see front matter
PII: S0304-3894(99)00014-X

located at the Deseret Chemical Depot (formerly known as Tooele Army Depot) in Utah. The chemical agents in the stockpile at Deseret Chemical Depot include blistering agent (also known as mustard agent and designated as H, HT or HD) and nerve agents designated as GB and VX. These agents are contained in munitions or bulk containers. The munitions containing these agents include rockets, land mines, projectiles and mortars. The bulk containers include ton containers (TC), spray tanks and non-explosively configured bombs.

The U.S. Congress has given the Department of Army the responsibility to destroy the stockpile of the chemical agents. The army has selected incineration as the preferred technology for disposal of the agent stockpile at sites storing munitions as well as bulk containers. The Tooele Chemical Agent Disposal Facility (TOCDF) is one of these incineration facilities located at the South Area of the Deseret Chemical Depot. There are five different incinerators at this facility. They include deactivation furnace system (DFS), metal parts furnace (MPF), two liquid incinerators (LICs) and a dunnage incinerator (DUN). The sheared explosives are processed in the DFS. The drained agent is burned in the LICs. The metal casings contaminated with residual agent after draining are processed through MPF for decontamination and contaminated waste may be processed through DUN or one of the other incinerators.

The Tooele Chemical Agent Disposal Facility is governed by RCRA regulations. The surrogate trial burns were prerequisites for the agent trial burns by Utah Division of Solid and Hazardous Wastes (UDSHW) for each incinerator. The surrogate burns for the Deactivation Furnace System were conducted in September/October, 1995. The purpose of the surrogate burns was to demonstrate the ability of the deactivation furnace system to destroy thermally stable surrogate compounds at more stringent destruction and removal efficiency than the chemical agents. A second purpose was to evaluate the capacity of the pollution abatement system to remove regulated pollutants from the stack exhaust gases. This approach assures that the system is adequately shaken down prior to introducing any lethal chemical agent into the system. The results from these surrogate trial burns (STB) are presented in this paper.

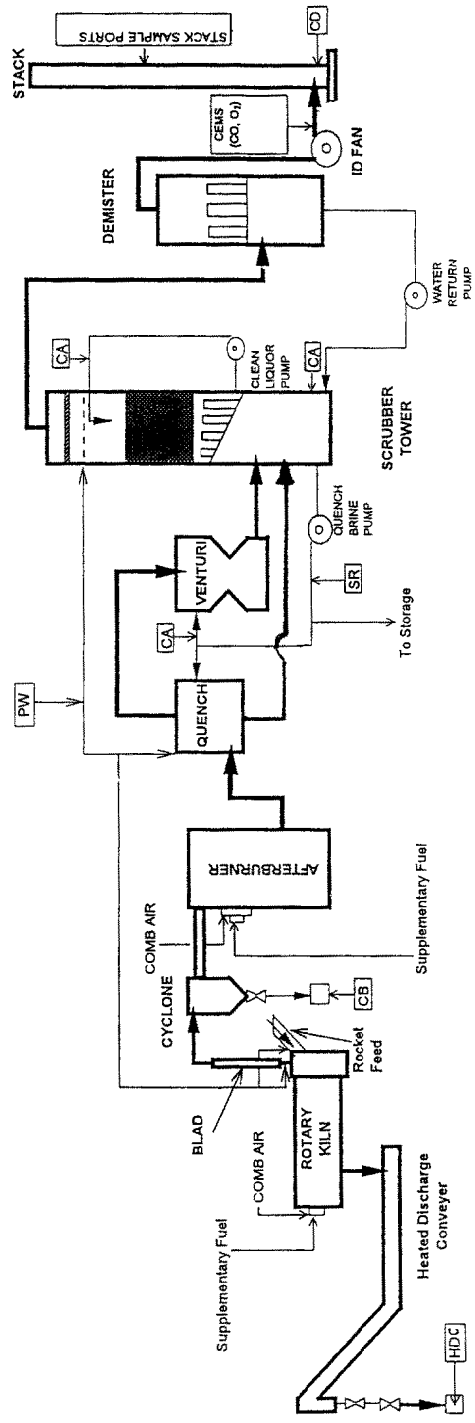
2. Equipment

The DFS includes the incinerator and the pollution abatement system. The system is designed to operate remotely through the control room. The programmable logic controllers are used to control the feeding operation and process conditions. Fig. 1 depicts the process flow schematic with the sampling locations.

2.1. Deactivation furnace incinerator (DFI)

The DFI includes the following major components:

- Rotary kiln
- Heated discharge conveyor (HDC)



SAMPLING LOCATIONS:
CA - NaOH MAKEUP - Sampled in the Bulk Chemical Storage (BCS) Area
CD - STACK CONDENSATE
PW - PROCESS WATER
CB - CYCLONE RESIDUE
SR - WET SCRUBBER RECIRCULATION BRINE
HDC - HDC RESIDUE

Fig. 1. Deactivation furnace process flow and sampling locations.

- Blast attenuation duct
- Cyclone
- Afterburner (AFB)

2.1.1. Rotary kiln

The rotary kiln is a cylindrical vessel of alloy construction and equipped with a spiral flight inside for positive material movement. It is the primary chamber for incineration process. It has a variable speed drive and rotates from 0.5 to 2 rpm. It has two feed chutes which merge into a single charge end assembly to permit feed from either of two shear machines in separate explosive containment rooms (ECRs). Each feed chute is equipped with two gates which operate sequentially to assure that one gate is closed at all times. A gas fired burner is mounted at the kiln's discharge end sub-assembly. The discharge end subassembly also directs the solid discharge from the kiln into the HDC. An insulated shroud which surrounds the rotary kiln minimizes heat transfer into the room with 24″ thick concrete walls which houses the kiln and HDC.

2.1.2. Heated discharge conveyor (HDC)

The HDC is an electrically heated chain-driven bucket conveyor. A part of the conveyor runs horizontally and the remainder is inclined as shown in Fig. 1. It serves as a part of the primary chamber for the incinerator. The discharge end of the HDC passes through the concrete barrier. There are two gates at the discharge end of the HDC. The HDC is connected through a discharge chute to the blast enclosure. A waste bin inside the blast enclosure collects the processed material dropped from the HDC buckets. The waste bins are changed at a prescribed interval to avoid overfilling. This interval is based on the number of munitions processed.

2.1.3. Blast attenuation duct (BLAD)

The Blast Attenuation Duct (BLAD) is located in the ductwork between the rotary kiln and the cyclone. Baffles inside the BLAD are designed to prevent any damage to the downstream equipment from an accidental blast inside the rotary kiln.

2.1.4. Cyclone

The cyclone is located upstream of the afterburner to remove particulate carried in the gases leaving the rotary kiln. Processing of rockets with fiberglass shipping tubes generates considerable amount of particulate from fiberglass. The particulate material is collected in a drum located at the bottom of the cyclone. The drum is housed inside an enclosure to control fugitive emissions during drum change out.

2.1.5. Afterburner

The afterburner is a refractory lined vessel equipped with two gas fired burners mounted near the top of the chamber. The flue gases from the cyclone enter the afterburner and are heated to the operating temperature. The afterburner is the secondary chamber for incineration process. It is designed to provide at least two second residence

time for complete combustion of the rotary kiln exhaust gases. The exhaust from the afterburner is directed to the quench tower.

2.1.6. Incinerator operating conditions

The rotary kiln is operated at 1100°F at the burner end, but the temperature at the feed end varies from 950 to 1600°F during feeding operation. A considerable amount of heat is generated from the rapid burning of explosive materials. A water spray is provided in the duct from the kiln to the cyclone to control the gas temperature below 1600°F that provides protection for the metallic duct work. The rotary kiln is controlled at −0.5″ w.c. Temperature inside the HDC is maintained at 1100°F. The HDC speed provides a minimum of 15 min residence time to assure detoxification of the material discharged from the kiln. Temperature in the afterburner is maintained above 2050°F.

2.2. Pollution abatement system (PAS)

The exhaust gases from the PAS for the DFS enters a common stack for the four wet PASs at TOCDF. The components of the DFS PAS include:

- Quench tower
- Venturi scrubber
- Scrubber tower
- Demister vessel
- Main and emergency induced draft fans

2.2.1. Quench tower

The quench tower is a vertical, cylindrical vessel of Hastelloy construction. Multiple banks of spray nozzles are located at the top for cooling the incinerator flue gases which enter at the bottom of the tower. A brine solution is circulated to the sprays at the top of the quench tower from the bottom reservoir in the scrubber tower. A portion of the brine which does not evaporate drains back into the scrubber bottom. The process water system supplies emergency quench water to the quench to cool the gases in the event that the brine recirculation system fails. It also supplies make up water to replenish water evaporated during quenching operation.

2.2.2. Venturi scrubber

The Hastelloy venturi scrubber is equipped with a variable throat to maintain constant differential pressure as the gas flow from the incinerator varies. Brine from the scrubber bottom reservoir is circulated to multiple radial and tangential nozzles above the venturi throat. The venturi atomizes the brine which in turn removes the majority of the particulate and acids which result from the incineration process.

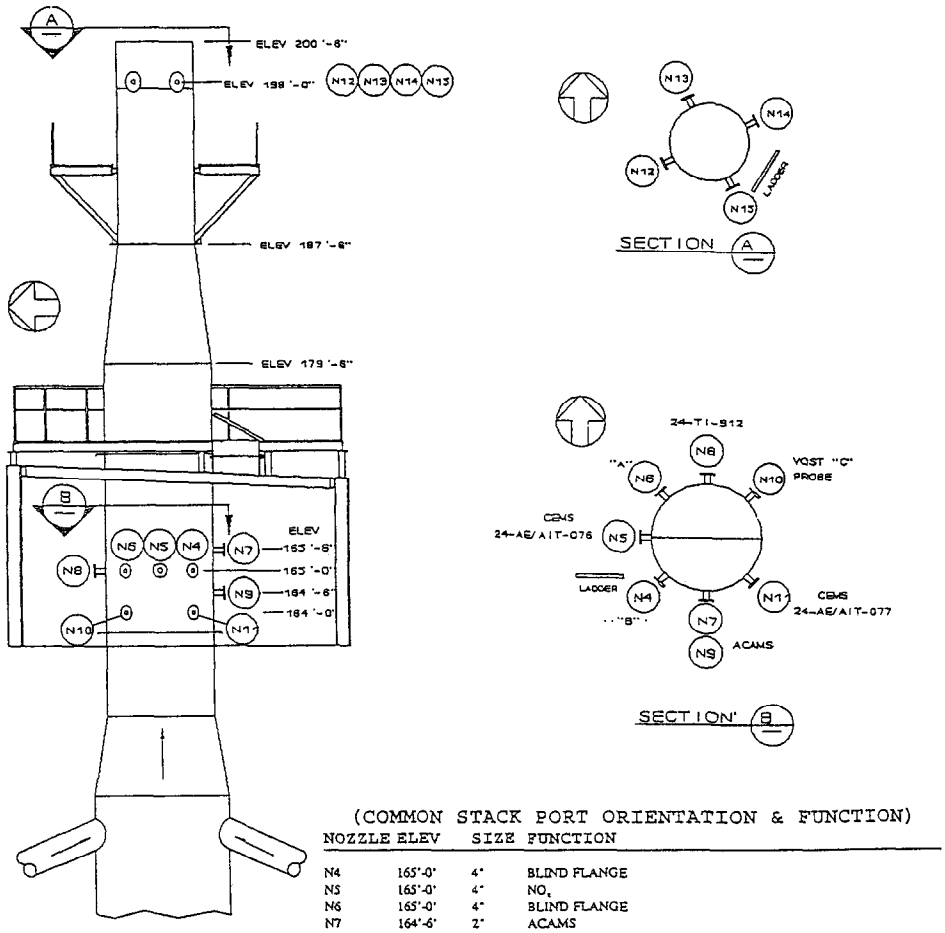
2.2.3. Scrubber tower

The scrubber tower is a cylindrical, Hastelloy vessel with a reservoir at the bottom to collect brine, a chimney tray to collect clean liquor, and a packed bed section for

scrubbing. The chimney tray serves as a second reservoir for clean liquor storage and recirculation. A mist eliminator pad located at the top of the scrubber tower prevents moisture carry-over to downstream equipment. An 18% caustic solution is added to the brine and clean liquor loops for pH control. Process water is added to the brine and clean liquor loops to maintain liquid levels and densities. A portion of the brine liquid is discharged to the brine reduction area (BRA) also for control of density.

2.2.4. Demister vessel

The demister is a cylindrical, fiberglass vessel with multiple vertical candle elements. The candles filter the incinerator flue gases and primarily remove sub-micron particulate



(COMMON STACK PORT ORIENTATION & FUNCTION)

NOZZLE	ELEV	SIZE	FUNCTION
N4	165'-0"	4"	BLIND FLANGE
N5	165'-0"	4"	NO_x
N6	165'-0"	4"	BLIND FLANGE
N7	164'-6"	2"	ACAMS
N8	165'-6"	1-1/2"	TEMPERATURE INDICATOR
N9	165'-6"	2"	ACAMS
N10	164'-0"	4"	BLIND FLANGE VOST - VOLATILE POHCs
N11	164'-0"	4"	ACAMS
N12	197'-6"	6"	BLIND FLANGE - ISO KINETIC SAMPLE TRAINS
N13	197'-6"	6"	BLIND FLANGE
N14	197'-6"	6"	BLIND FLANGE
N15	197'-6"	6"	BLIND FLANGE - ISO KINETIC SAMPLE TRAINS

Fig. 2. Common stack sampling ports.

which was not removed in prior scrubbing. Water spray is provided to wash solids which accumulate on the surface of the candles. The candles are replaced when pressure drop across them becomes excessive (greater than 15″ w.c.).

2.2.5. Main and emergency induced draft fans

Two induced draft fans are provided to move the incinerator combustion flue gases through the incinerator and PAS and into the common stack. The fans are provided with a variable position inlet butterfly damper which is modulated to control furnace pressure. A smaller emergency fan is also provided for the DFS. This fan is operated on emergency generator power. Thus, during electrical main power loss, the system can be maintained under negative pressure by the emergency fan. It also allows operations to fire one burner in the afterburner and maintain operating temperature in the afterburner.

2.2.6. PAS operating conditions

The gases flow from the quench to the venturi and then through the scrubber tower and the demister to the common stack. The ID fans provide the motive force for gas movement through the system. Gas temperature is cooled to below 200°F in the quench tower.

Brine is circulated from the bottom of the scrubber tower to the quench and venturi. The clean liquor is recirculated around the packed bed. The brine and clean liquor flows are controlled at specified levels. The pH of brine and clean liquor is controlled at 8.0. The pressure drop across the venturi is normally controlled at 30″ w.c. but the induced draft fan has enough capacity to increase the venturi pressure drop to 45″ w.c.

3. Surrogate materials

Trial burns with surrogate materials were required by UDSHW prior to the agent trial burns to assure that the system was adequately debugged and ready to process chemical agent. The performance criteria for STB were more stringent than for the chemical agents. The destruction and removal efficiency (DRE) required for the selected principal

Table 1
Sample collection summary

Sampling location	Sampling method	Collection frequency	Sample volume
Stack port N-10	VOST	6 Pairs/run	20 l/sample
Stack port N-12/N-15	M0010	1/run	90 dscf
Stack port N-12/N-15	M0050	1/run	90 dscf
ID fan outlet	O_2 and CO CEMS	Continuous	NA
Brine pump discharge	Tap	Every 30 min	2–40 ml vial
Caustic pump discharge	Tap	1/run	1–40 ml vial, 1–500 ml bottle
Process water inlet	Tap	1/run	1–40 ml vial, 1–500 ml bottle
Stack condensate drain	Tap	1/run	1–40 ml vial, 1–500 ml bottle
Cyclone discharge	Scoop	1/STB	1–500 ml bottle
HDC discharge	Scoop	1/STB	1–500 ml bottle

Table 2
Surrogate usage

Run #	Total bags	HCE [lb]	MCB [lb]	Total [lb]
3	513	1042.42	2588.60	3631
4	530	1071.66	2650.0	3722
5	729	1460.92	3644.27	5105

Total for three surrogate runs—12458 lbs.

organic hazardous constituents (POHC) as surrogates was 99.9999% instead of 99.99% for chemical agents. The selection criteria for the surrogate materials were as follows:

(a) Must have a Class I compound from the list based on Thermal Stability Index published by EPA.
(b) Must have a volatile organic compound (VOC)
(c) Must have a semivolatile organic compound (SVOC)
(d) Must have a solid compound
(e) Must have a compound with relatively low heat of combustion (high in the list based on heat of combustion for difficulty of incinerability).

Based on the above criteria two POHCs were selected as surrogate materials. These were monochlorobenzene (MCB) and hexachloroethane (HCE).

Material packaged for the trial burn was a combination of 5 lb liquid MCB in a 2-l plastic bottle and 2 lb solid HCE in a polyethylene bag. Both of these were placed in a burlap bag to make a feed batch. Each batch was fed into the deactivation furnace at an interval of 30.5 s.

4. Sampling and analysis

The exhaust gases from the DFS were sampled and analyzed for VOC, SVOC, particulate, hydrogen chloride, oxygen and carbon monoxide. Multiple sampling ports were provided on the stack to allow sampling of stack gas. Fig. 2 shows the sampling port locations. Gas samples were collected using three different sampling trains at ports N10, N12 and N15. These sampling trains were prepared in accordance with the approved EPA methods for sampling. The ports N7, N9 and N11 are for automatic continuous agent monitoring system (ACAMS). Process liquids and solid residue samples were also collected during these trial burns. Fig. 1 depicts the sampling locations for all samples. Table 1 summarizes the sampling method, frequency of sampling and sample volumes for various types of samples collected during these tests.

Notes to Table 3:
[a]Removal efficiency (%).
[b]Chlorine input from organic compounds.
[c]PM emissions [grains/dscf] corrected to 7% O_2.
[d]PM emission rate [lb/h] corrected to 7% O_2.
[e]Run average of CO ppmv corrected to 7% O_2, (1 h rolling average).

Table 3
DFS performance summary

Performance date of run				10/5/95	10/5/95	10/6/95	Compliance limit met
Average gaseous flow rate [dscfm]				9392	8682	8899	
Surrogate materials/ regulated materials	State of Utah Permit Section	Feed input	State of Utah permit limit	Run #3 (P-3)	Run #4 (P-4)	Run #5 (P-5)	
Chlorobenzene (MCB)	VI.C.2.d	593 [lb/h]	99.9999% DRE	99.999990			Yes
		575 [lb/h]	99.9999% DRE		99.999967		Yes
		588 [lb/h]	99.9999% DRE			99.999999	Yes
Hexachloroethane (HCE)	VI.C.2.d	239 [lb/h]	99.9999% DRE	99.999989			Yes
		229 [lb/h]	99.9999% DRE		99.999988		Yes
		237 [lb/h]	99.9999% DRE			99.999991	Yes
Hydrochloric acid (HCl)	VI.C.2.d	401 [lb/h][b]	4 [lb/h]	0.0183 [lb/h] 99.996[a]			Yes
		386 [lb/h][b]	4 [lb/h]		0.0532 [lb/h] 99.987[a]		Yes
		397 [lb/h][b]	4.00 [lb/h]			< 0.0040 lb/ h > 99.999[a]	Yes
Particulate matter (PM)	VI.C.2.d		0.08 [grains/ dscf]	0.0043[c]	0.0048[c]	0.0049[c]	Yes
				0.312[d]	0.306[d]	0.326[d]	Yes
Carbon monoxide (CO)	VI.C.2.d		100 ppmv corrected to 7% O_2	10[e]	10[e]	10[e]	Yes

Table 4
Particulate/HCl emissions

STB run number	FO (9/30)	P-3 (10/5)	P-4 (10/5)	P-5 (10/6)
Stack flow rate [ACFM]	27649	31426	28710	29347
Stack flow rate [DSCFM]	8655	9501	8680	9003
% water vapor, volume basis	50.89	52.72	52.85	52.06
% CO_2, vol.	4.7	8.0	8.1	7.2
% Oxygen, vol. (Orsat)	12.4	8.5	9.0	8.9
Total sampling time [min]	120	120	120	120
% Isokinetic	95.4	101	102	100
Sample volume [DSCF]	82.520	95.916	88.451	90.094
Particulate mass [g]	0.00038	0.0238	0.0237	0.0247
Particulate Rate [grains/dscf]	0.0007	0.0038	0.0041	0.0042
Particulate corrected to 7% O_2 [grains/dscf]	0.0011	0.0043	0.0048	0.0049
HCl [mg/sample]	1.1	1.4	4.1	ND
HCl [lbs/h]	0.0152[a]	0.0183	0.0532	< 0.004
Chlorine [mg/sample]	ND	0.8	3.5	ND
Chlorine [lb/h]	ND	0.0105	0.0454	ND
HCl removal efficiency, %	NA	99.996	99.987	99.999

[a]The blank for this sample had higher chloride levels than the sample, therefore, this value is an estimated maximum.

The sampling and analysis were performed by an outside contractor. The oxygen and carbon monoxide concentration data were collected by continuous emission monitoring system (CEMS).

5. Results

A total of five test burns were conducted with the surrogate feed and one burn was conducted with firing fuel (natural gas) only (FO) to the burners with no feed. The first

Table 5
Wet scrubber brine samples, [μg/l]

Analyte	FO	P-3	P-4	P-5
MCB	< 0.15	< 0.15	< 0.15	< 0.15
HCE	< 0.55	< 0.55	< 0.55	< 0.55
Arsenic	< 300	< 300	< 300	< 300
Barium	110	< 20	< 20	< 20
Cadmium	58	< 5	< 5	< 5
Chromium	4600	4400	4600	2300
Lead	< 100	< 100	< 100	< 100
Selenium	< 300	< 300	< 300	< 300
Silver	< 10	< 10	23	20
Aluminum	20000	460	< 200	1300
Nickel	9000	590	160	1100
Mercury	< 0.02	< 0.02	< 0.02	< 0.02

Table 6
Stack condensate, [μg/l]

Analyte	FO	P-3	P-4	P-5
MCB	< 0.15	< 0.15	< 0.15	< 0.15
HCE	< 0.55	< 0.55	< 0.55	< 0.55
Arsenic	< 300	< 300	< 300	< 300
Barium	< 20	< 20	< 20	< 20
Cadmium	< 5	< 5	< 5	< 5
Chromium	< 10	< 10	< 10	38
Lead	< 100	< 100	< 100	< 100
Selenium	< 300	< 300	< 300	< 300
Silver	< 10	< 10	< 10	< 10
Aluminum	< 200	< 200	< 200	< 200
Nickel	< 40	< 40	< 40	< 40
Mercury	< 0.02	< 0.02	< 0.036	< 0.02

two burns were aborted due to sampling and equipment problems. During Run 1 cross contamination of probes rinse occurred during sample recovery, so the run was aborted. During Run 2 a weldment failure in the feed chute was observed, which resulted in aborting that run. The results reported are for the test runs 3 to 5. Duration for each trial burn was from 4 to 6 h. The surrogate materials burned during each trial burn is summarized in Table 2. Performance of the DFS for DRE of VOC chlorobenzene and SVOC hexachloroethane, for removal of HCl and particulates and for emission of CO is summarized in Table 3 for runs 3 to 5. The DRE values for both POHC exceeded the regulatory requirement of 99.9999%. The maximum DRE for MCB was 99.999999 and for HCE was 99.99999. The scrubber efficiency for removal of HCl far exceeded the requirement of 99% removal or less than 4 lb/h emission. The maximum efficiency observed was greater than 99.999%. The particulate emissions varied from 0.0043 to 0.0049 grains/dscf compared to the regulated value of 0.08 grains/dscf. The carbon monoxide emissions were 10 ppm, which is a factor of 10 lower than the allowable rate of 100 ppm.

Table 7
DFS residue samples

Analyte	HDC [mg/l]	Cyclone [mg/l]
MCB	< 0.005	< 0.005
HCE	< 0.1	< 0.1
Arsenic	< 0.5	< 0.5
Barium	0.73	0.20
Cadmium	< 0.01	< 0.01
Chromium	< 0.02	0.42
Lead	< 0.10	< 0.10
Selenium	< 0.30	< 0.30
Silver	< 0.02	< 0.02
Aluminum	< 0.20	11
Nickel	31	28
Mercury	< 0.0002	< 0.0002

The details for stack gas flows and % isokineticity along with HCl and particulate emissions for each run are described in Table 4. The isokineticity was within the required range of 90 to 110%. The analyses for the liquid samples for scrubber brine and stack condensate are presented in Tables 5 and 6. All the components in the scrubber brine samples were below detection limit except for chromium, nickel and aluminum. The levels for these three components in the brine for fuel-only run were higher than those in the brines for trial runs. Thus it is suspected that these components are due to corrosion of metallic walls and erosion of refractory in the afterburner. The stack condensate had all components below detection limit except for one sample which showed chromium above detection limit.

The TCLP analysis of solid residue samples from the HDC and the cyclone are shown in Table 7. Barium and nickel were the only metals above detection limit in the HDC residue. The cyclone residue had chromium and aluminum in addition to barium and nickel above the detection limit.

6. Conclusions

The surrogate trial burns have successfully demonstrated that performance of the DFS at TOCDF was excellent and surpassed all the performance criteria established by the UDSHW. The specific results achieved were:

- DRE for MCB and HCE varied from 99.999967 to 99.999999%, which was considerably higher than required DRE of 99.9999.
- HCl removal efficiency was 99.99% compared to the required efficiency of 99%. Thus it was a factor of 100 better.
- Carbon monoxide emissions were a factor of 10 better. Observed values were 10 ppm compared to the permitted value of 100 ppm.
- Particulate emissions were significantly lower (by a factor of 16) than the permitted value of 0.08 grains/dscf.
- The concentration of MCB, HCE and TCLP metals in the liquid and solid residue samples were mostly either below the detection limit or lower than the values for *fuel only* burns.
- The health risk estimated from these emissions by UDSHW was lower than the original estimate prior to these tests.

The UDSHW had thoroughly reviewed the surrogate burn report and concluded that the deactivation furnace system was capable of meeting the DRE requirements for the chemical agents. An approval to proceed with the preparations for GB agent trial burns was granted. The GB agent trial burns were subsequently conducted in January, 1997.

Acknowledgements

The author thanks the office of Program Manager for Chemical Stockpile Disposal (PMCSD) in Aberdeen, MD for their support and permission to publish this paper. The author also thanks all the personnel who helped in preparing and reviewing this document.