Pollutant Emission Factors for a Transportable Detonation System for Destroying UXO

By

William J. Mitchell
USEPA (MD-46)
Research Triangle Park, NC 27711
(mitchell.william@epa.gov)

Todd Borci, StephenYee, Alan Hicks
USEPA Region 1
Boston, MA
(borci.todd@epa.gov, yee.steve@epa.gov, hicks.alan@epa.gov)

Gary Simpson
Shield Environmental Associates Inc.
Lexington, KY (Gary_Simpson@shieldmw.com)

Howard Schiff
TRC Environmental Solutions, Inc.
Lowell, MA
(hschiff@trcsolutions.com)

A Paper for Presentation At The UXO Countermine Forum
New Orleans, LA
April 9-12, 2001

ABSTRACT

The U.S. Environmental Protection Agency (EPA) discourages the disposal of unexploded ordnance (UXO) by open air and soil-covered detonations, because these processes cause toxic metals, organics and explosives to be released into the environment. This paper presents the results from an emissions testing study on an alternative UXO disposal technology (DeMil International Model T-10 transportable contained detonation system) while it was destroying 81-mm mortar rounds at the Massachusetts Military Reservation. The emissions testing showed that more than 98.8% of the Zn and more than 99.99% of the Cu, Mg, Mn, Fe and Al in the mortar rounds were retained in the T-10 and that the particulate emissions were 150 times less than those from an open air detonation. The emissions testing also showed that, if explosive and their degradation products were present, they were below the detection limit (i.e., 1 nanogram/gram of explosive detonated) of the measurement system.

INTRODUCTION

The EPA has issued an Administrative Order to the National Guard Bureau (NGB) requiring the remediation of contamination, including UXO, at the Massachusetts Military Reservation (MMR). The U.S. Army Corp of Engineers (USACE) is conducting this UXO remediation effort on behalf of the NGB. The MMR sits over the aquifer from which communities on Cape Cod draw their drinking water. Before the remediation effort began, tests determined that the aquifer already had undesirable concentrations of TNT, RDX and metals. Thus, destroying the UXO by open air or soil covered detonations, traditional UXO disposal procedures, was not a preferred approach, because it could cause additional contamination of the aquifer. This concern was particularly heightened by the fact that many of the UXO uncovered would be training and experimental items which might not detonate cleanly.

In 1999, DeMil International, Huntsville, AL developed a transportable version of its Donovan contained detonation chamber (CDC) technology for use in destroying UXO. In January 2000, the Department of Defense Explosive Safety Board approved DeMil's Model T-10 CDC system for destroying ordnance containing up to the equivalent of 5.9 kg of TNT. In May 2000, the USACE began using a Model T-10 for destroying UXO at the MMR. At the same time, the USEPA and the USACE began to collaborate on an effort to characterize the emissions from the T-10 while it was destroying UXO at the MMR. The objectives of this study were: (1) to confirm (using actual UXO found at the MMR) that the emissions from the T-10 were below the levels which would endanger human health and the environment; and (2) to develop emission factors which could be used to develop permit conditions for the T-10 operating at MMR and also used at other remediation sites to obtain permits for destroying UXO with the T-10.

The emission testing was conducted in January 2001 while the T-10 was being used to destroy 81-mm mortar rounds. This paper presents the pollutant emissions factors obtained at the MMR for the T-10 system and compares them to emission factors from other studies involving the detonation of explosive containing items.

DESCRIPTION OF THE T-10 TRANSPORTABLE CONTAINED DETONATION SYSTEM

The T-10 System at the MMR has three components: a detonation chamber; an expansion chamber; and an air pollution control unit (APCU), i.e., a Torit Industries, Model TD573, cartridge filter baghouse with a 0.3 m^3 hopper and a 73 m^3/minute fan.

The detonation chamber has a double wall fabricated from A-36 grade steel plate. Its exterior dimensions are 2.0 m wide, 2.0 m long, and 2.1 m high. The interior wall is lined with hardened, abrasion resistant armor plate and the space between the walls is filled with dry silica sand. The weight of the chamber with silica sand is approximately 18,400 kg. UXO items can be destroyed in the T-10 at intervals as frequent as five minutes apart. During operation, the floor of the chamber is covered with 12 cm (0.35 m^3, 500 kg) of pea gravel and thin-walled plastic bags containing water are placed inside the chamber. The pea gravel and water are used for two reasons. First, they attenuate the shock wave, over-pressure and hot gases released by the detonation, thereby protecting the integrity of the chamber. Second, they release wet dust particles and water droplets which serve as nuclei for the detonation products to adhere to, which aids in the collection of the emission products by the APCU. Unfortunately, the water also quenches the detonation fireball and prevents the second stage of the detonation process (incineration) from occurring.

The gases and particles released by the detonation vent into the single walled, steel expansion chamber which has interior dimensions of 2.5 m x 2.5 m x 2.5 m. This chamber is reinforced with channel steel for strength and weighs 2,400 kg. It both attenuates the over-pressure and heat remaining from the detonation and also aids in the removal of particles and condensible materials from the detonation gas stream.

SELECTION OF MUNITION TO BE USED IN TEST

The 1700 UXO destroyed to date in the MMR T-10 included: mortars (60 and 81 mm); rockets (2.36 and 3.5 inch); projectiles (30, 37, 57 and 75 mm); rifle grenades; and fuzes. The M-374, 81-mm mortar was selected for the emissions tests for the following reasons. First, it has the largest explosive mass (0.95 kg Comp B) of all the munitions destroyed at MMR. Second, it is at the upper design limit for fragment hazards for the T-10 System. Third, it is one of the most frequently found UXO items at the MMR. Fourth, many of the 81-mm mortars found at the MMR are training and experimental rounds which contain an inert material rather than high explosive. Theoretically, these training and experimental rounds, many of which are painted blue to distinguish them from those containing high explosives, should not have to be detonated. However, the reality is that some of the suspected inert rounds found at the MMR do contain explosives. Therefore, it is standard practice to detonate all MMR UXO items for which a positive determination can not be made. Thus, it was decided to use both regular and suspected inert mortars in the study. The plan was to detonate regular high explosive (HE) mortars in the first set of detonations and suspected inert training mortars in the second set of detonations and then compare the emission products.

The body of the 81- mm mortar is made of a mild steel (97.5% Fe, 1.75% Mn, and trace level of C, S, Si and P) and weighs 2.3 kg. The fin assembly is made of an aluminum-copper alloy (92.2% Al, 4.5% Cu, 0.80% Mn, 0.85% Si, 0.7% Fe, and small amounts of Mg, Zn, Ti, and Cr) and weighs 0.11 kg. Pentaerythritol tetranitrate (PETN) was used as the donor charge as part of the testing effort. For this study, the typical mass ratio of donor charge to ordnance item charge for the T-10, which is 1:1, was used for both types of mortar rounds.

COLLECTION OF THE PLUME SAMPLES

Because the T-10 UXO destruction process is a batch operation, it was decided to collect 20 to 50% of each detonation plume (after it left the APCU) in a temporary, 14 m^3 Plume Capture Box (PCB) which was made by wrapping a 2 x 4 wood frame with re-enforced plastic and then to sample the captured plume for 15 to 25 minutes. This plume collection was accomplished as follows. After the detonation, the APCU discharge fan was turned off. Filtered, pressurized air was then fed into the detonation chamber for approximately four minutes to push the plume through the expansion chamber/APCU, and into the PCB. A 19-cm diameter duct carried the plume from the baghouse exit to the PCB. To ensure that the quantities of the emission products collected would exceed the minimum quantitation limits (MQL) of the analysis methods, composite samples representing five detonation plumes were collected. (The PCB was purged with ambient air between each of the five detonations.) To obtain both a measure of the precision of the sampling methods and to compensate for any non-homogeneous distribution of the emission products in the box, two pollutant sampling systems of each type located on opposite sides of the PCB were used. The nozzle of each sampling probe was extended approximately 45-cm into the PCB at a height of 1.3 m above the ground.

As part of the test program, Sudhakar, the USACE contractor, and DeMil International operated the T-10 System, while Shield Environmental Associates in conjunction with Air Tech Environmental, LLC, performed the sample collection. Other specialty subcontractors used included; Oregon Graduate Institute (OGI), who prepared certain sampling apparatus (TO-14 Method Trains) and performed the laboratory analyses for CO, CO_2, HE, and VOCs, and Severn Trent Laboratories(in Austin, TX and Sacramento, CA), who performed the metals, particulates, semi-volatile organic compounds (SVOCs) and energetics analyses of the emissions samples.

PLUME VOLUME TRACER

At the instant of detonation, a Tedlar bag containing a known mass of helium which was in the detonation chamber ruptured and released He into the detonation plume. The concentration of He found in the gas samples collected from the PCB was then used to estimate the total quantity of the detonation plume that had been collected in the PCB, so that emission factors for each analyte could be calculated using the methodology which is described in the CALCULATION OF EMISSION FACTORS section later in this paper.

SAMPLING AND ANALYSIS METHODS

The detonation pollutant emission products were determined using USEPA sampling and analysis methods described in 40 CFR, Part 60, Appendix A[1] and EPA SW-846[2]. These methods were selected based on the composition of the 81- mm mortars and on the results from studies which measured the emissions from detonated explosives.[3, 4, 5, 6, 7]

PARTICULATE (PM) AND METAL EMISSION PRODUCTS.

These samples were collected and analyzed using EPA Method 29. The target metal analytes were Fe, Al, Mg, Mn, Cu, Ni, Zn, and Cr. PM was determined as the sum of the material collected on a pre-weighed filter and any material recovered from the acetone rinse of the front half of the train components. After the PM mass was determined, the filter and any residue from the evaporated acetone probe rinse were digested with dilute acid and hydrogen peroxide to solublize any metals present. This solution was then filtered, combined with the impinger contents, and an aliquot was then taken and analyzed for the target metal analytes using EPA SW-846 Method 6010B (inductively coupled argon plasma emission spectroscopy).

NON-EXPLOSIVE, SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCS).

These compounds were collected using EPA SW-846 Method 0010 and analyzed by EPA SW-846 Method 8270C . Method 0010 consists of a heated probe, a quartz filter, a chilled condenser, a solid sorbent resin (XAD-2) and a series of impingers containing water. At the conclusion of sampling the filter, XAD-2 cartridge, impinger solutions and probe wash samples were recovered and sent to the laboratory where they were extracted in a Soxhlet apparatus using dichloromethane and the extract analyzed by GC/MS.

ENERGETIC SEMI-VOLATILE ORGANIC COMPOUNDS.

These compounds were also collected and recovered in a manner similar to that used for the non-energetic SVOC compounds (i.e., Method 0010), but they were extracted using methylene chloride and analyzed using a modified version of USEPA SW-846 Method 8330 (liquid chromatography/mass spectrometry, LC/MS).

HELIUM (TRACER), CO, CO_2, AND VOLATILE ORGANIC COMPOUNDS (VOCS)

These analytes were collected in Tedlar bags. At the conclusion of sampling, a pump was used to transfer sample from the Tedlar bag into a clean, evacuated canister until the pressure in the canister equaled two atmospheres. The canister was then sent to the laboratory where the concentrations of the gases present were determined with the following methods: EPA Method 25 for CO and CO_2; EPA Method TO-14 (GC/FID and GC/MS) for VOCs, including ethylene and acetylene; and GC/TCD for He.

NITROGEN OXIDES

The NO_x concentration in the PCB was measured on a real time basis using chemiluminescence monitors operated according to the procedures in EPA Method 7E. Sample gas was withdrawn from the PCB from two locations by separate pumps and transported through Teflon tubing to monitors located in the instrument trailer.

CALCULATION OF EMISSION FACTORS

After the concentration of each emission product and the He tracer were corrected to 25 ^{0}C and one atmosphere pressure, they were converted into emission factors (g of analyte/g of explosive detonated) using equation 1.

$$EF_i = (f_{He})[\text{analyte } i]/[He_j] \qquad (1)$$

where:

EF_i = emission factor of target analyte i (in g/g NEW)

f_{He} = total mass of He released over the five detonations divided by the total mass of explosive used in the five detonations

[analyte i] = concentration (e.g., in mg/m^3) of the analyte sample collected from the PCB for that series of detonations

$[He_j]$ = concentration (e.g., in mg/m^3) of He in the PCB for the time the emission sample was taken.

SULTS AND DISCUSSION

The masses of He used in the first and second set of detonations were 12.84 g and 13.88 g, respectively and the corresponding, background-corrected He concentrations in the PCB were 47.9 mg/m^3 and 48.4 mg/m^3, respectively. (These He concentrations indicate that for both detonations approximately 23% of the plume was captured in the PCB.)

The plan was to detonate regular HE mortar rounds in the first set of detonations and suspected inert training mortar rounds containing wax in lieu of HE in the second, so that the emission products from the two types of mortars could be compared. Unfortunately, based on the intensity of the blast noise and an inspection of the metal remaining in the chamber after each detonation, both types of mortars were detonated in each set. (After a high explosive filled round was detonated, generally only a few very small pieces of the casing were found in the chamber. In contrast, when training rounds were detonated, a fair amount of the tail fin and some of the casing remained along with deposits of wax.) That is, two of the five regular HE mortars were incorrectly marked and were actually inert training mortars, and one of the training mortar rounds turned out to be a regular HE mortar round. To compensate for this, the NEW values used in Equation 1 for the first and second set of detonations were 7.582 kg and 5.720 kg, respectively.

Table 1 presents the emission factors obtained from the MMR T-10 emission tests. (Note: if a semi-volatile or energetic target analyte is not included in this table, the reader should assume that it was either not detected or was not detected above the background concentration.) The emission factors from the first set of detonations (mortars supposedly containing Comp B) are identified as MMR-1 and those from the second set (training mortars containing wax) are identified as MMR-2. The values in the last column of Table 1 were obtained by dividing the MMR-1 emission factor by the corresponding MMR-2 emission factor, to determine if there were consistent relationships between the emission factors from the two sets of detonations..

An inspection of Table 1 shows that there are very noticeable differences between the MMR-1 and MMR-2. For example, the MMR-1 emission factors for Al, Cu, Mg, Mn, Fe and Zn are 2 to 46 times larger than the corresponding MMR-2 emission factors. This is consistent with the observation that the detonation completely destroyed the casing and tail fin of the explosive-filled mortar rounds, but not that of the wax-filled ones. Also, the MMR-1 VOC emission factors are consistently larger than the corresponding MMR-2 emission factors. This also is not surprising since Comp B was not observed in the detonation chamber after the detonation but wax residues were.

One of the primary reasons that EPA discourages using soil-covered and open air detonation of UXO is to prevent toxic metals and explosives from entering the environment. The T-10 emission factors for the metals clearly demonstrate that it prevented both explosive residues and metals from entering the environment. For example, none of the target energetic (explosive) analytes were found (detection limit was 1 ng/g of explosive detonated). Also, the results for the metals show that the following percentages of the metal in the mortar were retained in the T-10 system: (1) MMR-1 (99.99% Al, 99.97% Cu, 99.996% Fe, 99.996% Mn, 99.5% Mg and 98.8% Zn); and (2) MMR-2 (99.999% Al, 99.999% Cu, 99.999% Fe, 99.999% Mn, 99.9% Mg, and 99.8% Zn).

There have been a number of studies[3, 4, 5, 6, 7] where explosives were detonated in chambers and the emission products measured. These studies can be placed into three categories based on the extent to which the fireball, the second stage of the detonation process, is allowed to form. The first category (Fireball Formation Prevented) applies to studies in which the chamber dimensions and plastic bags containing water placed in the chamber with the explosive prevented the fireball from forming, e.g., the 105 mm and 4.2 inch mortars detonated in the DeMil International D-100 stationary CDC system at the Blue Grass Army Depot (BGAD) and the DDI CDC system in Danvers, IL. The second category (Fireball Partially Suppressed) applies to studies in which the chamber dimensions shortened the life of the fireball, e.g., the bare TNT detonations in the ODOBi chamber at Dugway Proving Ground, UT and the 155-mm detonations in the X-tunnel at the Nevada Test Site (NTS). The third category (Normal Fireball) applies to studies in which a normal fireball is produced, e.g., those conducted in the BangBox at Dugway Proving Ground, UT.

Table 2 presents emission factors obtained for TNT and RDX-containing materials in these other studies and Table 3 presents some percentages which were calculated from the emission factors in Tables 1 and 2. The information in Tables 2 and 3 has been provided to give the reader the opportunity to compare the MMR T-10 emission factors to those obtained in other studies. To aid in this comparison, the emission factors in Table 2 have been placed into the three categories identified in the previous paragraph.

A comparison of the data in the three tables provides some interesting information. For example, the CO and unsaturated VOC emissions from detonations in which the fireball was prevented from forming are considerably higher than those in which the fireball was allowed to form, but the aromatic (VOC) and SVOC compounds are approximately the same. Also, the emission factors for particulate for the CDC systems at MMR and BGAD, which are equipped with baghouses, are considerably lower than those from the other chambers studied. Table 3 also shows that in every study, 98% of the unsaturated hydrocarbon emissions were represented by just three compounds (acetylene (A), ethylene (E) and propene (P)) and that (with the exception of the BangBox tests), 98% of the aromatic compounds were represented by just two compounds (benzene (B) and toluene (T)).

CONCLUSIONS

Although the results reported here cover only one type of ordnance item, they demonstrate that the detonation chamber technology has the potential to be used for UXO clearance at a wide variety active and closed military facilities. It should also be a viable alternative destruction technology to the soil-covered and open air detonation processes which are used at some U.S. Army facilities to destroy less than 100 tons of ordnance a year.

REFERENCES

1 Title 40 of the Code of Federal Regulations, Part 60 - Appendix A. Reference Methods 7E, 25 and 29.

2. Test Methods for Evaluating Solid Waste Physical/ Chemical Methods, Volume III. SW-846 Methods 0010, 8270, 8330. U.S. Environmental Protection Agency, Office of Solid Waste, Washington, DC.

3. Mitchell, William J. and Jack Suggs, Emission Factors for the Disposal of Energetic Materials by OB/OD. EPA Report Number - EPA/600/R-98/103. August 1998.

4. ODOBi Air Sampling Test Report. Prepared by Radian International LLC, Oak Ridge TN for the U.S. Army Dugway Proving Ground, UT. December 1997. (DPG POC - RJ Black, 435-831-3825).

5. Department of Defense/Department of Energy Joint Demilitarization Technology Demonstration Program: Executive Summary of Phase I Demonstrations- Detonation of Conventional Weapons - 155 mm High Explosive M-107 Projectiles In the NTS X-Tunnel. Lawrence Livermore National Laboratories Report Number UCRL-ID-131252. July 1998.

6. BGAD (Blue Grass Army Depot) Detonation Chamber Data Collection Test Report, Phases I and II. Prepared for DeMil International, Inc. by El Dorado Engineering, Inc. 2964 West 4700 South, Suite 109, Salt Lake City, UT 84118, August 2000.

7. Mitchell, William J., Thomas E. Ward and RJ Black. Improving the Environmental Safety of Munitions Disposal by OB and OD. In Proceedings of the Fifth Global Demilitarization Symposium and Exhibition, Reno, NV. May 1997.

Disclaimer

The views expressed in this paper are those of the individual authors and do not necessarily reflect the views and policies of the United States Environmental protection Agency (EPA). Scientists in EPA have prepared sections of this paper based on only a preliminary review of the study results, and therefore, their sections may be revised at some time in the future. This paper has been reviewed in accordance with EPA's peer and administrative review policies and approved for presentation and publication.

TABLE 1. Emission Factors from the MMR T-10 Tests

ANALYTE	EMISSION FACTOR (g/g NEW)		MMR-1/MMR-2
	MMR-1	MMR-2	
CO_2	8.4E-01	1.0E+00	0.8
CO	8.3E-02	9.7E-02	0.8
NOx	6.0E-04	8.0E-04	0.8
Methane	7.9E-03	4.6E-03	1.7
Hydrogen	9.3E-03	5.1E-03	1.8
Particulate	6.1E-04	1.7E-04	3.6
TNMHC	1.5E-02	1.0E-02	1.4
Acetylene	5.7E-03	3.9E-03	1.4
Ethylene	4.7E-03	3.7E-03	1.3
Propene	8.5E-04	6.0E-04	1.4
All Unsaturated HC	1.1E-02	8.5E-03	1.3
Benzene	1.8E-03	9.0E-04	2.0
Toluene	1.7E-04	7.5E-05	2.3
Styrene	2.5E-05	1.0E-05	2.5
All Aromatic HC	2.0E-03	1.0E-03	2.0
Naphthalene	1.5E-05	1.6E-05	0.9
Phenol	1.5E-07	1.9E-07	0.8
Phenanthrene	1.9E-07	ND	-
Pyrene	1.9E-07	ND	-
Benzoic Acid	3.5E-07	4.4E-07	0.8
Aluminum	9.6E-06	9.3E-07	10
Copper	9.2E-07	4.3E-07	2.1
Magnesium	1.7E-06	4.5E-07	3.8
Manganese	8.7E-07	1.3E-07	6.9
Iron	6.5E-05	1.4E-06	46
Zinc	2.2E-06	4.2E-07	5.2

TABLE 2. Selected Emission Factors (g/g NEW) from Other Chamber-based Detonation Studies

ANALYTE	FIREBALL FORMATION PREVENTED			FIREBALL DURATION SHORTENED		NORMAL FIREBALL
	BGAD-1	BGAD-2	DDI	ODOBI	NTS	
CO_2	a	a	b	5.0E-01	7.5E-01	1.5E+00
CO	5.7E-02	1.7E-02	1.5E-01	4.7E-03	4.0E-02	1.2E-02
NOx	8.5E-03	3.5E-03	a	2.1E-02	1.4E-05	1.5E-02
Particulate	3.0E-04	1.2E-04	a	a	6.2E-03	1.7E-01
TNMHC	a	a	8.5E-03	2.4E-04	2.1E-04	7.0E-04
Acetylene	a	a	1.3E-03	2.0E-05	3.2E-05	1.3E-04
Ethylene	a	a	8.3E-04	1.2E-05	6.8E-05	5.4E-05
Propene	a	a	1.2E-04	1.9E-06	3.3E-05	8.2E-06
All Unsat'd HC	a	a	2.9E-03	3.6E-05	a	3.3E-04
Benzene	7.5E-05	2.3E-05	9.6E-04	2.5E-05	5.0E-05	8.9E-05
Toluene	1.1E-05	2.5E-06	2.0E-04	2.0E-06	1.0E-05	3.3E-05
All Aromatic HC	a	a	1.1E-03	2.7E-05	a	3.3E-04
Naphthalene	4.0E-06	3.8E-07	a	7.4E-07	3.1E-06	a
Phenol	1.0E-06	b	a	9.1E-07	b	b
Benzoic Acid	b	b	a	4.4E-06	b	b
2,4-DNT	b	b	a	1.4E-05	b	b
TNT	b	b	a	1.5E-03	b	b
RDX	b	b	b	b	1.4E-05	b
Aluminum	b	b	b	b	a	7.1E-03

(NOTE - In Table 2 an (a) means that the analyte was either not measured, not calculated or not valid, and a (b) means that the analyte was not detected.)

TABLE 3. Selected Ratios From Chamber Studies

RATIOS	MMR-1	MMR-2	DDI	ODOBi	NTS	BangBox
% C in Explosive Converted to COx	41%	a	a	37%	92%	99%
% CO/(CO + CO_2)	9.0%	8.6%	a	0.9%	5.1%	0.8%
% N in Explosive Converted to NOx	0.1%	0.2%	a	3.4%	0.2%	1.6%
% (A + E + P)/ Unsaturated HC	98%	96%	77%	95%	a	95%
% (B + T)/Aromatic HC	98%	98%	110%	98%	a	38%

(NOTE - In Table 3 an (a) means that the analyte was either not measured, not calculated or not valid.)

Subcontractor List:

Shield Environmental Associates, Inc.
2456 Fortune Drive Suite 100
Lexington, KY 40509
(859) 294-5155
Gary_Simpson@shieldmw.com
Scope: Prepared Test Plan, coordinated testing and analytical effort, collected VOCs, He, CO, and CO_2 samples, and prepared test report.

Air Tech Environmental, LLC
3714 S. Alston Avenue
Durham, North Carolina 27713-1804
(919) 544-6338
answers@ipass.net
Scope: Collected metals, particulates, SVOCs, and energetic samples, analyzed particulate samples and prepared test report.

Oregon Graduate Institute (OGI)
Department Environmental Science and Engineering
20000 NW Walker Road
Beaverton, Oregon 97006
(503) 690 B1077
rei@ese.ogi.edu
Scope: Prepared TO-14 sampling trains, prepared helium tracer gas system, and analyzed VOCs, He, CO, and CO_2 samples.

Severn Trent Laboratories (STL)
Austin, TX and Sacramento, CA
14046 Summit Drive, Bldg. B
Austin, TX 78728
(512) 244-0855
Scope: Analyzed metals, SVOCs, and energetic samples.

The Highland Group
PO Box 161206
Austin, TX 78716-1206
(512) 306-1584
dpm@flash.net
Scope: Provided QA/QC review of analytical results (metals, SVOCs, and energetic samples).