

FINAL REPORT

Feasibility of New Technology to Comprehensively Characterize
Air Emissions from Full Scale Open Burning and Open
Detonation

SERDP Project WP-1672

DECEMBER 2010

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Center

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Abstract

For many decades, Open Burning/Open Detonation (OB/OD) has been used as a safe and economic munitions demilitarization for energetic material disposal. Field OB/OD air emissions have been very difficult to characterize because of rapid dispersion, short event duration, heterogeneous emission concentrations, large plume lift, soil entrainment, and explosion safety restrictions. In response to a 2009 SERDP Statement of Need, this project was designed to develop a new emission measurement system for comprehensive air emission characterization for full-scale OB/OD operations.

The project team developed a field campaign plan and conducted the field campaign at Tooele Army Depot, Utah, in March 2010. Emissions from OB of M1 propellant and OD of TNT were sampled over a three week period. This report describes the execution and results of the field campaign and discusses the feasibility of the emission measurement system to characterize air emissions from full-scale OB/OD. Close coordination with the DoD demilitarization community enabled the research team to produce useful data for demilitarization-related compliance issues and operations.

The feasibility study consisted of *in situ* and optical remote sensing (ORS) sampling, analysis and monitoring. The *in situ* sampling configuration included fixed position samplers, and airborne sampling. The aerial platform used a balloon-lofted instrument package called the “Flyer”. The instrument pack was lofted with a He-filled balloon and maneuvered by two tethers connected to two all-terrain-vehicles (ATVs). Continuous measurements of CO₂ and co-sampled PM-10, volatile organic compounds, and semi-volatile organic compounds allowed determination of emission factors.

The ORS system included active and passive open-path Fourier Transform Infrared (OP-FTIR) spectrometers, Ultraviolet Differential Absorption Spectrometers (UV-DOAS), and a Micropulse Light Detection And Ranging (LIDAR) (MPL). The ORS samplers were complemented with Tapered Elemental Oscillating Microbalance (TEOM) measurements. The system was designed to measure PM-10 with TEOMs and a MPL; and gaseous pollutants with active and passive OP-FTIR and UV-DOAS systems.

Results indicated that (1) the Flyer was an effective tool to measure PM-10 and gaseous air emissions from OB/OD, (2) the MPL-based system monitored the cross section of the entire plume and could monitor PM-10 with or without TEOM measurements after an average PM-10 mass extinction efficiency value was established through TEOM and MPL readings, (3) the active OP-FTIR was able to detect a few gaseous emissions and (4) UV-DOAS and passive OP-FTIR were not an effective monitoring tool for measuring gaseous emissions. Overall, we have successfully completed the field campaign and provided results that determined the feasibility of the deployed measurement systems.

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List of Acronyms

<u>Term</u>	<u>Definition</u>
1-D	one-dimensional
2-D	two-dimensional
AAP	Army Ammunition Plant
AMCCOM	US Army Armament, Munitions and Chemical Command
AP42	USEPA Compilation of Air Pollutant Emission Factors
APS	aerodynamic particle sizer
ATV	all terrain vehicle
BC	background corrected
BLDC	brushless direct current
CCS	Chemical Compliance Systems, Inc.
CEM	continuous emissions monitor
CFR	Code of Federal Regulations
DAC	U.S. Army Defense Ammunition Center
DoD	Department of Defense
DPG	Dugway Proving Grounds
DNT	2,4-dinitrotoluene
EDXRF	energy dispersive x-ray fluorescence spectrometry
EF	emission factor
ERDC-CERL	Engineer Research Development Center, Construction Engineering Research Laboratory
GC/FID	gas chromatograph(y) - flame ionization detector
GC/MS	gas chromatography/mass spectroscopy
GPS	global positioning system
HE	high explosive
IS	internal standard
LIDAR	light detection and ranging
L/min	liters per minute
MACS	Munitions Analytical Compliance System
MDL	minimum detection limit
MEE	mass extinction efficiency
MPL	micropulse light detection and ranging (LIDAR)
NEW	net explosive weight
NDIR	nondispersive infrared
NOAA	National Oceanic and Atmospheric Administration
NRB	normalized relative backscatter
NRMRL	USEPA National Risk Management Research Laboratory
OB	open burning
OD	open detonation
OBODM	OB/OD Dispersion Model
OP-FTIR	open-path Fourier transform infrared spectrometer
OP-LT	Open path laser transmissometer
ORS	optical remote sensing

<u>Term</u>	<u>Definition</u>
PAH	polycyclic aromatic hydrocarbon
PIC	path-integrated concentration
PM	particulate matter
PM-2.5	particulate matter that is 2.5 micrometers or smaller in size
PM-10	particulate matter that is 10 micrometers or smaller in size
ppb	parts per billion
ppm	parts per million
PUF	polyurethane foam
QA/QC	quality assurance/quality control
R3	resource recovery or recycling
RCRA	Resource Conservation and Recovery Act
RDX	hexahydro-1,3,5-trinitro-1,3,5 triazine
RPD	relative percent difference
RSD	relative standard deviation
SERDP	Strategic Environmental Research and Development Program
SIM	selective ion monitoring
SON	Statement of Need
SVOC	semi-volatile organic compound
TEOM	tapered elemental oscillating microbalance
TNT	2,4,6-trinitrotoluene
UIUC	University of Illinois-Urbana Champaign
USEPA	United States Environmental Protection Agency
UV-DOAS	ultraviolet differential absorption spectrometers
VOC	volatile organic compound
XRF	X-ray fluorescence

1. Introduction

1.1 Project Overview

U.S. Department of Defense (DoD) Installations, especially demilitarization facilities and Army Ammunition Plants (AAPs), have long used Open Burning/Open Detonation (OB/OD) as a safe and economic means to dispose of propellants, explosives, and waste military munitions. DoD installations are required to comply with the Resource Conservation and Recovery Act (RCRA) to operate OB/OD facilities. RCRA permits provide annual limits on the amount of energetic materials that can be disposed of at OB/OD facilities. The permit limitations are based on human health risk assessments that include risk estimates from airborne exposure to emissions generated from OB/OD. These assessments have used emission factors developed from open atmosphere testing as well as from a small-scale OB/OD chamber known as a BangBox®. Improvements to the methods and equipment for conducting open atmosphere air emissions testing for OB/OD can help to continually validate these emission factors as well as produce a larger set of good quality emission factors that address known data gaps. Field OB/OD air emissions have been very difficult to characterize because of rapid dispersion, short event duration, heterogeneous emission concentrations, large plume lift, soil entrainment, and explosion safety restrictions.

The title of the Strategic Environmental Research and Development Program (SERDP) FY2009 Statement of Need (SON) was “Characterization of Emissions from Open Burn/Open Detonation.” The SON’s objective was “to seek applied research leading to improved quantification of all atmospheric emissions from the demilitarization of ordnance via OB/OD.” The research team developed a comprehensive 4-year proposal that responded to the majority of the issues presented in the SON. The SON included the following issues:

- Development of measurement methodologies that will accurately characterize the emissions from OB/OD operations. Measurement methodologies/techniques that are developed must demonstrate robustness and repeatability. (Main objective of this project)
- Development of prediction capabilities to accurately predict emissions from OB/OD operations for a wide and representative variety of ordnance and munition items, thereby eliminating the need to perform detailed emission measurements for all items that could be demilitarized.

At the review of the original SERDP proposal, the SERDP Science Advisor Board directed the project team to develop a 1-year feasibility study proposal incorporating input from all DoD stakeholders. The one-year feasibility study proposal “Feasibility of New Technology to Comprehensively Characterize Air Emissions from Full Scale Open Burning and Open Detonation” was approved by the SERDP Office and work began on the project late in FY09.

The project team developed a new conceptual framework for comprehensive air emission characterization under real world conditions, and conducted a field campaign in March 2010. This report describes the execution and results of the field campaign and discusses the feasibility of the newly proposed conceptual framework to characterize air emissions from full-scale OB/OD.

Close coordination with the DoD demilitarization community enabled the research team to produce useful data for demilitarization-related compliance and operations.

1.2 Objectives

The objectives of this project are to:

1. Develop a new conceptual framework for comprehensive air emission characterization from full-scale OB/OD operations.
2. Evaluate the feasibility of the new air emission characterization technologies under real field conditions.
3. Use the new technology to characterize air emissions from OB operations using M1 propellant and from OD operations using 2,4,6-trinitrotoluene (TNT).
4. Document a plan for continuing OB/OD emission characterization research using the newly developed measurement technology to fill in data-gaps in the current emission factor databases.

1.3 Report Outline

In response to guidance from the U.S. Army Defense Ammunition Center (DAC) and other advisors, we determined to conduct the feasibility field campaign at Tooele Army Depot using M1 propellant for OB and TNT flake for OD air emissions characterization. These materials were chosen because there is ample data on emissions from OB/OD of these materials in the current emission factor database. We designed an integrated plume characterization system that combined a tethered balloon for aerial sampling and optical remote sensing (ORS) that included a light detection and ranging (LIDAR) system and visible, infrared, and UV spectrophotometer systems. DAC and the research team chose a limited set of target analytes, selected from those for which emission factors exist and for which there is a reasonable degree of confidence, and is sufficient to satisfy the technology demonstration purposes of this project. The selected target analytes for this project were benzene, naphthalene, lead, and particulate matter (PM).

Chapter 2 describes air characterization equipment, sampling techniques, measurement techniques, analysis methods, and estimation methodologies. Chapter 3 presents field campaign data and critical discussion of results. Chapter 3 included discussion topics on how well the plume was measured under changing meteorological conditions, the comparison of results among systems and with published information, the ways that the measurement systems and results can complement each other, and lessons learned. Chapter 4 summarizes the feasibility study and presents the future needs for air quality characterization from full-scale OB/OD operation based on current technology and data gaps.

The project team conducted a field campaign 8-26 March 2010 at Tooele Army Depot, UT. Appendix A contains the USEPA Quality Assurance Project Plan, and Appendix B contains the University of Illinois and ENVIRON's Test Plan.

1.4 Background

1.4.1 OB/OD Overview

DoD installations use OB/OD as a safe and economic means to dispose of explosive materials, which can be either “high” or “low” explosives. High explosive materials decompose very rapidly; the detonation process moves through the material at supersonic speeds, creating a shock wave. Low explosive materials (propellants and pyrotechnics) decompose at a subsonic rate, creating no shock wave. Table 1-1 lists open burning/open detonation (OB/OD) facilities in the United States (Cramer 2009). The large number of facilities listed in Table 1-1 indicates that OB/OD is still a very prevalent practice in the United States.

Table 1-1. OB/OD disposal units in the United States.

Operational OB/OD Units Nov 2009	
Service	Installation
Demilitarization Mission	
US Army	McAlester AAP, OK
US Army	Hawthorne AAP, NV
US Army	Tooele Army Depot, UT
US Army	Deseret Chemical Depot Tooele, UT
US Army	Anniston Army Depot, AL
US Army	Letterkenny Munitions Center, PA
US Army	Blue Grass Army Depot, KY
US Navy	NSWC Crane, IN
USAF	Hill AFB, UT
Manufacturing Mission	
US Army	Radford AAP, VA
US Army	Milan AAP, TN
US Army	Holston AAP, TN
US Army	Iowa AAP, IA
RDT&E Mission	
US Army	Redstone Arsenal, AL
US Army	Dugway Proving Grounds, UT
US Army	Picatinny Arsenal, NJ
US Army	Yuma Proving Grounds, AZ
US Army	Aberdeen Proving Grounds, MD
US Navy	NAWC China Lake, CA
US Navy	NSWC Dahlgren, VA
US Navy	NWS Charleston, SC
US Navy	SUBASE Kings Bay, GA
US Navy	NSWC Indian Head, MD
US Navy	NSWC EODTECHDIV, MD
US Navy	NWS Earle, NJ
USAF	Eglin AFB, FL
USAF	Kirkland AB, NM
USAF	Holloman AFB, NM
USAF	Vandenberg AFB, CA
USAF	Edwards AFB, CA
USMC	MCAS Beaufort, SC
USMC	MCAS Yuma, AZ

OB/OD is regulated by 40 CFR Part 264, Subpart X: Miscellaneous Units. This RCRA regulation requires that OB/OD facilities have a Subpart X permit for the disposal of explosive hazard-

ous waste. To ensure the RCRA Subpart X permit applications are protective of human health and the environment the emission factor data needs to be as accurate and complete as practical.

The SERDP Statement of Need (SON) #WPSON-09-02 identified some major technical issues, e.g., analytical and sampling methodology issues, and the fact that more complete open atmosphere test results can help to further evaluate small-scale studies to ensure they serve as representative of full-scale OB/OD operations.

As it stands, conservative approaches have been taken in the interpretation and application of available OB/OD emission factors data for RCRA permitting. Some examples of the resulting permitting issues include:

- limiting OD treatment to times when typical winds will not potentially impact nearby offsite receptors (i.e., based on typical wind direction conditions, OD treatment was limited to only 40 percent of available hours),
- limiting treatment to only those munitions items with applicable emission factors available
- requirements to prepare extensive (and costly) risk assessments to compensate for overly conservative OB/OD emission assumptions that result from unavailable emission factors.

1.4.2 Historical Review of Understanding Air Emissions from OB/OD

DoD Agencies, particularly DAC, have a long history in research and development (R&D) efforts in air emissions from OB/OD. A half century ago, Ornellas was a pioneer characterizing detonations products. Between 1961 and 1981, Ornellas conducted a series of bomb calorimeter detonation experiments designed to determine how various factors affected the efficiency and effectiveness of the detonation process (Ornellas 1982). His experiments established that the major reaction products from an unconfined detonation were N₂, CO₂, and H₂O, and that the minor products were CO, H₂, CH₄, NO, NO₂, HCN, HCl, HF, and volatile organic compounds (VOCs). The first comprehensive DoD study to characterize air emissions from real world OB/OD operations was conducted at Dugway Proving Grounds from 1984 through 1986. In 1988, the U.S. Army conducted a follow-on study in the BangBox® at Sandia National Laboratories. Based on these test results, DoD concluded that the emission factors for the predominant emission products produced in the BangBox® emission tests were statistically equivalent to those produced in the Dugway Proving Grounds open range tests and also those produced by Ornellas, which showed that the emission products did not change substantially, even when the quantity detonated increased 32,000 times. In 1992, the USEPA concurred with these DoD conclusions and agreed to accept BangBox® produced emission factors as representative of those that would be derived through ground level, open air detonation, and burn tests. Work by Lindsay et al. (1999) employed blimp sampling at Hill Air Force Base in 1998 and 1999 to characterize emissions from open detonations. The emissions were sampled via canisters, silica tubes, and Teflon filters suspended from the blimp for CO₂, VOCs, chloride analyses, and PM. The tests were only partially successful, and showed the potential for this type of sampling platform. The authors made significant suggestions for improvements.

DAC teamed up with Los Alamos, Lawrence Livermore, Sandia National Laboratories, and Oregon Health Sciences University to conduct a full-scale OB/OD air emission characterization using remote sensing that was performed at Socorro, NM during September 2001. The tests were part of a program called “Enhancing Techniques for Open Burn/Open Detonation (OB/OD) of Conventional Munitions” funded by DAC. The tests included the use of balloons, LIDAR, and passive open-path Fourier Transform Infrared (OP-FTIR) spectrometry. The LIDAR was successful in tracking and visualizing the plume geometry, the balloons were only partially successful due to handling problems, and the passive OP-FTIR tests that relied on infrared radiation from within the plume were not able to record meaningful data in part because of the small temperature difference between the plume and the surrounding atmosphere.

DoD has submitted a draft AP-42 chapter to USEPA that contains OB/OD air emission factors. This submission was thoroughly reviewed by DoD stakeholders before submission and is in the final stage of review by the USEPA. The compilation of OB/OD emission factors found in the draft AP-42 Chapter 16 were obtained from the emissions characterization studies referenced above. These studies included testing on an open test range and in a BangBox® at Dugway Proving Grounds between 1989 and 1995 (U.S. Army, AMCCOM, 1992(a-f); Mitchell et. al., August 1998). In the open range study, an instrumented airplane was used to collect samples from the plumes produced from OD and OB. For the detonation work, 2000 lb of bulk high explosives (HE) were open detonated. For the open burning work, 4600 to 7000 lb of five individual propellant materials were burned in steel pans on a test range. In the BangBox® study, air sampling equipment located inside the BangBox® and in a building attached to it was used to collect samples from the plumes. For the detonation work, 0.3 to 0.5 lb of bulk HE and munitions were detonated. For the open burning work, 2.2 to 5.0 lb quantities of propellants were open burned on a bed of pea gravel in a stainless steel pan sitting on a steel pad located in the center of the Bang-Box®.

The draft Chapter 16 of AP-42 contains tables showing emission factors and emission factor quality ratings for both OB and OD operations. The USEPA quality rating codes for the emission factors range from A (excellent) to D (below average). A large majority of emission factors are rated C or better. Emission factors with a D rating include PM with particle diameters < 10 µm (PM-10) from OD and metals from OD. The proposed Chapter 16 has no emission factors for PM-2.5 emissions and emissions from soil covered OD.

2. Materials and Methods

This project developed a new conceptual framework for measuring full scale OB/OD emissions and for testing the feasibility of the new technology. Testing occurred at Tooele Army Depot and included measuring emissions from both OB and OD. Plume measurement systems included a combination of ORS and in situ plume measurements using ground-based, mobile, and aerial sampling.

The research team consisted of members with interdisciplinary specialties and various experiences in OB/OD, ORS, and air pollution source sampling, from:

- The Engineer Research Development Center, Construction Engineering Research Laboratory (ERDC-CERL),
- University of Illinois-Urbana Champaign (UIUC),
- ENVIRON, and
- The USEPA National Risk Management Research Laboratory (NRMRL).

Throughout OB/OD's long history, the demilitarization community, particularly DAC, has been heavily involved in R&D efforts for emission factor development. In this feasibility study, DAC, its consultants, along with demilitarization community support (Table 2-1) has greatly helped to improve the quality of the research project.

Table 2-1. Technical advisors' contributions.

Team Member	Affiliation	Contribution
Ryan Williams and Tyrone Nordquist	DAC and Joint Ordnance Commanders Group Demilitarization and Disposal Subgroup	Point of contact for demilitarization community; Coordinated with Tooele Army Depot and JOCG Subgroup. Provided financial support to cover field preparation costs
Dr. Randy Cramer	Naval Ordnance Safety and Security Activity and JOCG Environmental Subgroup	Coordinated with the DoD Joint Ordnance Commanders Group (demil and environmental committees)
Dr. Eric Erickson	Naval Air Warfare Center-Weapons Division, China Lake	Analytical chemistry and sampling experience with regard to OB/OD operations.
Tony Livingston	Joint Munitions Command	Army Joint Munitions Command representative
Dr. Bill Mitchell	Mitchell and Associates	Developer of AP-42OB/OD emission factors, currently in USEPA review
Dr. George Thompson	Chemical Compliance Systems, Inc.	Demil and emissions database manager (DAC's contractor)
Mr. Ryan Williams, Dr. Bill Mitchell, and Dr. George Thompson	U.S. Army Defense Ammunition Center (USADAC), Bill Mitchell and Associates, LLC, Chemical Compliance Systems, Inc.	Selected OB/OD items: M1 propellant and TNT for OD tests and coordinated with JMC for shipment of the test items

Team Member	Affiliation	Contribution
Roger Hale, Darwin Jones, and Cody Spencer	Tooele Army Depot.	Provided field assistance
Ron Stoner	Tetra Tech	Provided white paper to cover OB/OD air emission factor issues
Ken Schuster	USEPA Office of Solid Wastes	Organized phone conference to connect RCRA permit administrators through all USEPA Regional Offices
Tim Alexander	Army Environmental Command	Helped prepare initial proposal

2.1 Test Range and Ordnance

Figure 2-1 (supplied by Tooele Army Depot) shows a close-up map of the Test Range, which consists of an indoor facility (#1376), bunkers, a gravel/sand detonation area for open detonation tests (~330 ft × 165 ft, ~100 m × 50 m) and a concrete burn pad (~65 ft × 80 ft, ~20 m × 25m) for open burning tests. The Army determined the safety stand-off shown here as a function of charge size. The OB and the OD tests were video monitored and recorded from the indoor facility/bunker (#1376 in Figure 2-1). The barbed wire fence includes gates (marked) for an easy entry and exit of the sampling equipment, which was pre-positioned inside the safety standoff distance during ODs. The elevation at the Tooele Army Depot test range is about 5000 ft (1520 m) above sea level.

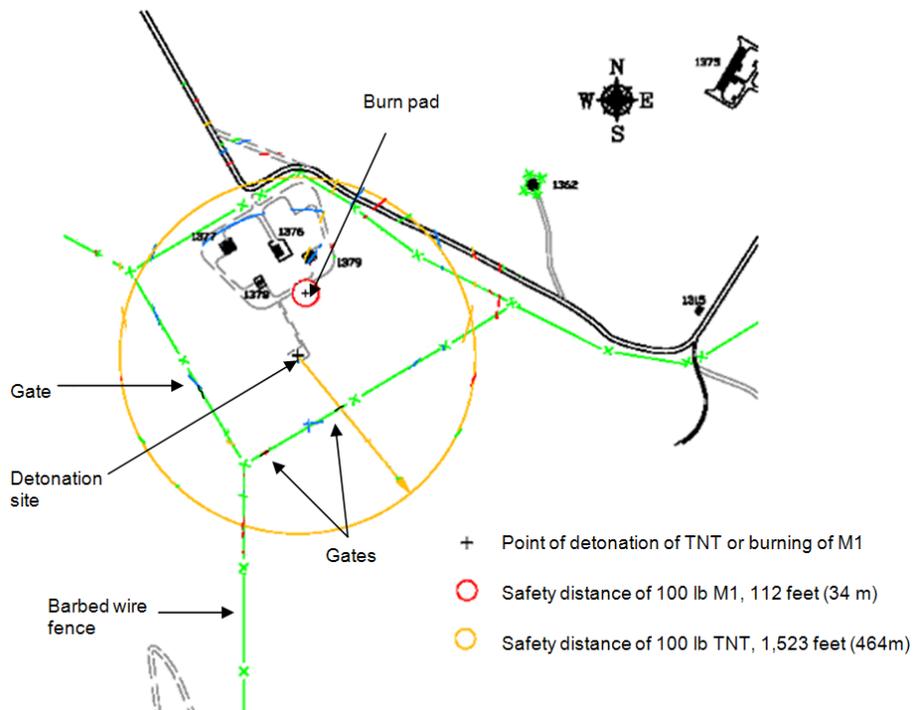


Figure 2-1. Tooele Army Depot test range map including safety standoff distances for OB of 100 lb (45.5 kg) M1 and OD of 100 lb (45.5 kg) TNT.

For this field campaign, samples were collected and emissions measurements were made for both OB of 100 lb (45.5 kg) M1 propellant and OD of 50 lb (22.7 kg) or 100 lb (45.5 kg) trinitrotoluene (TNT) flake. Black powder was used to initiate OBs and C4 to initiate ODs. Table 2-2 lists the composition of these materials (Army Armament Munitions and Chemical Command, 1992).

Table 2-2. Composition of ordnance and igniter material.*

Material	Mass %	Carbon Fraction %	Composition	
M1	84	25.7	Nitrocellulose	$C_6H_7(NO_2)_3O_5$
	9	46.2	2,4-dinitrotoluene (DNT)	$C_6H_3(CH_3)(NO_2)_2$
	5	69.0	Dibutyl phthalate (plasticizer)	$C_{16}H_{22}O_4$
	1	85.2	Diphenylamine	$(C_6H_5)_2NH$
	1	4.5	Lead carbonate	$PbCO_3$
Black Powder	75	0	Potassium nitrate	KNO_3
	15	100	Softwood charcoal	C
	10	0	Sulfur	S
TNT	100	37	Trinitrotoluene	$C_7H_5N_3O_6$
C4	91	16.2	RDX - Cyclotrimethylenetrinitramine	$C_3H_6N_6O_6$
	5.3	85.6	Plasticizer – polyisobutylene	C_4H_8
	2.1		Binder	
	1.6		SAE non detergent motor oil	
* Carbon fraction from (Army Armament Munitions and Chemical Command, 1992) with the exception of lead carbonate, RDX, and plasticizer which were calculated.				

2.2 In-situ Balloon and Scissor Lift Sampling

A series of 60 open burns of M1 propellant and 37 open detonations of TNT flakes were conducted at the Tooele Army Depot in Tooele, UT in March 2010. Aerial and scissor lift based sampling methods were used to sample emissions.

2.2.1 Aerial Sampling Method

The test used a balloon-borne instrument package and sampling method to collect the emissions. This aerial sampling method used two ground-based all-terrain vehicles (ATVs) with tethers and winches to anchor and maneuver a helium-filled balloon, which carried a lightweight sampling package termed “the Flyer” (Figure 2-2). The Flyer, is a loftable, instrument-bearing platform for the collection of batch gas and particle samples from ambient air or plumes, the collection of carbon dioxide (CO₂) via continuous emission monitors (CEM), and the logging of data. It includes programmable logic control hardware that enables sampling only when CEM data indicate that the Flyer is located within a plume. Replaceable, rechargeable batteries provided power. The Kingfisher (K13N) is a 13×10.3-ft (3.96×3.14m) diameter helium balloon (Figure 2-3) which lofted the ~25 lb (~11 kg) Flyer at Tooele Army Depot. The combination of two ATVs and two tethers permitted the positioning of the balloon equipped with the sampling platform at a specific location and height downwind of the burns and detonations.

The Flyer was configured for this project with a CO₂ CEM, volatile organic compounds (VOC) sampler with a Summa canister, semi-volatile sampling with a polyurethane foam (PUF)/XAD-2/PUF sorbent sampler, and with a PM-10 filter sampler. Due to the short sampling duration of each burn/detonation, the system was designed to collect composite samples for both semi-volatile emissions (PUF/XAD-2/PUF) and PM-10. The composite samples are created by reusing the same sorbent media or filter during multiple events. CEM data and flow rate were logged to an on-board HOBO[®], which also measured temperature and relative humidity (Figure 2-2). The Flyer also has an onboard global positioning system (GPS).

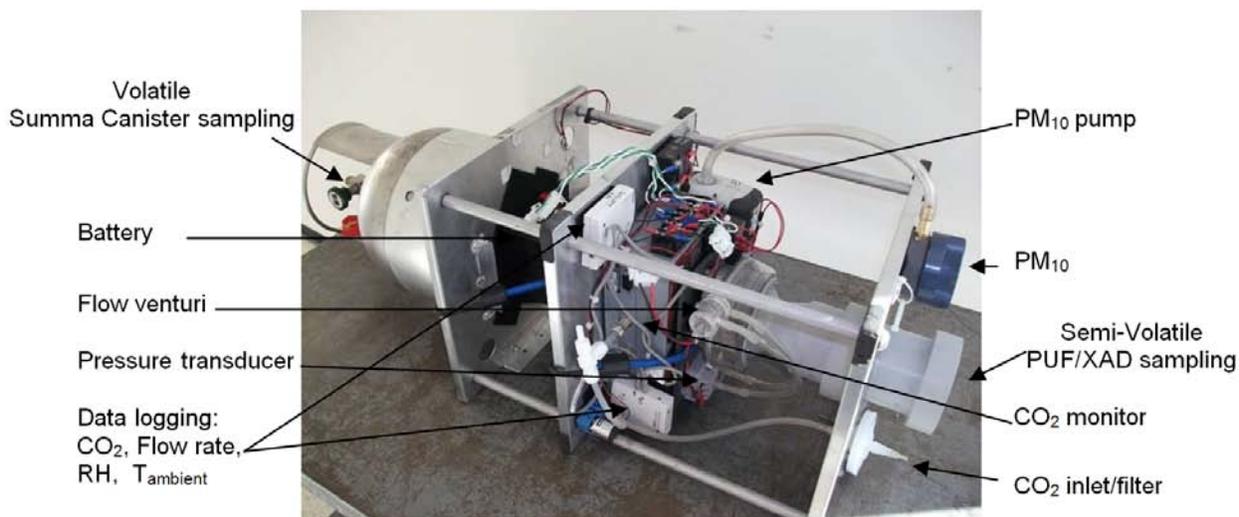


Figure 2-2. Instrumentation on the Flyer, GPS not in picture.



Figure 2-3. Balloon and Flyer (left) and balloon and ATV winch system (right).

2.2.2 Scissor Lift Based Sampling Method

Emissions from OB and OD of military ordnance were also sampled from the top of an extended scissor lift. The scissor lift had a maximum height of approximately 35 ft (11 m). Equipment on the scissor lift included a CO₂ CEM and a PM-10 impactor/filter sampler. The CEM data were logged to an on-board HOBO[®], which also measured ambient temperature plus relative humidity

(Figure 2-4). The purpose of this sampling equipment was to compare the PM-10 measurements from the ground-based path monitoring systems with those from the Flyer.



Figure 2-4. Scissor lift (left) and instrumentation on the scissor lift (right).

2.2.3 Testing and Sampling Procedures

2.2.3.1 Open Burn

The balloon and Flyer were prepositioned downwind or, in some cases, straight above the burn site with the aid of windssocks and vanes. The ATVs and all personnel remained outside the safety stand-off distance. Each ATV had a driver. The M1 propellant burns were ignited one by one when favorable winds approached. When necessary and possible, the balloon was maneuvered into the plume by reeling in the tether or by manually running the tethers down, as guided by visual observations. Six to nine re-usable, sheet steel pans were used in each burn series (Table 2-3); each of these burn pans contained 100 lb M1 propellant. The burn pans were positioned in two rows with three pans in each row (Figure 2-5). (Three backup pans were used to quickly position and ignite pans 7 to 9).

Table 2-3. OB test matrix.

Date	M1 (lb)	VOC, Summa Canister	Semi-volatiles, PUF/XAD-2/PUF	PM-10	CO ₂
3/10/2010			Background (upwind)		Background (upwind)
3/11/2010	6*100	X	X	X	X
3/12//2010	6*100	X			X
3/15/2010	6*100	X	X	X	X
3/16/2010	6*100	X	X	X	X
	6*100	X	X	X	X
3/17/2010	9*100	X	X	X	X
	9*100	X	X	X	X
3/17/2010		Background (upwind)			Background (upwind)
3/18/2010	9*100	X	X	X	X
	9*100	X	X	X	X



Figure 2-5. Concrete burn pad with six reusable sheet steel pans showing a burn of 100 lb (45.5 kg) of M1 propellant.

2.2.3.2 Open Detonation

Based on several pre-sampling detonations during the week of 8 March, it was determined that the effective shrapnel zones for the ATVs and the balloon to be approximately 300 ft (90 m) from the detonation. Furthermore, the shockwave created from the detonation was shown to have only minor effects, if any, on the balloon. The balloon and Flyer was pre-positioned downwind of the detonation site with the aid of windsocks. The ATVs and the balloon/Flyer were located inside the safety stand-off distance. All personnel were located outside of the stand-off distance and behind a protective bunker.



Figure 2-6. Detonation site, showing a fire ball from detonation of 100 lb (45.5 kg) of TNT, and the balloon with the flyer.

Four to five detonations were used in each detonation series. The charge size of each detonation varied between days (Table 2-4). For the first two days, all charge sizes were 50 lb (22.7 kg), while the last two days only the detonation placed closest to the balloon had the charge size of 50 lb (22.7 kg) all others were 100 lb (45.5 kg). Table 2-4 lists the test matrix for the open detonation tests.

Table 2-4. OD test matrix.

Date	TNT (lb)	VOC, Summa Canister	Semi-Volatiles, PUF/XAD-2/PUF	PM-10	CO ₂
3/19/2010	5*50	X	X	X	X
3/20//2010	9*50	X	X	X	X
3/22/2010	2*50 8*100	X	X	X	X
3/23/2010	3*50 10*100	X	X	X	X
3/24/2010		Background (upwind)	Background (upwind)	Background (upwind)	Background (upwind)

2.2.4 Emission sampling and analysis methods

The following sections describe the emission sampling methods and analytical methods for determination of CO₂, benzene, naphthalene, PM-10 by filter, and particulate-bound lead. Table 2-5 lists the emission sampling methods and the analytical methods used for the open burning and open detonation tests. The estimated sampling duration for each analyte was estimated to ensure detectable levels in the field sampling. These durations were estimated using the instrument sampling rate, analytical detection limits, published emission factors, and predictive open burn/open detonation dispersion model (OBODM) (SERDP 2004). Due to the short sampling duration of each burn/detonation, multiple events were used to create a single, composite sample for both semi-volatile (PUF/XAD/PUF) and PM-10. These single samples were created by reusing the same sorbent media or filter during multiple events.

Table 2-5. Target compounds and sampling and analysis methods.

Target Compound	Sampling Method	Sampling Rate	Analysis
Benzene	TO-15 Summa	2-3 L/min	GC/LRMS
Naphthalene	TO-13, PUF/XAD-2/PUF	250 L/min.	GC/LRMS
PM-10	Filter	10 L/min	Analytical Balance
Lead	Filter	10 L/min	Compendium Method IO-3.3, EDXRF
Carbon dioxide	CEM	Every second	NDIR CEM
Carbon dioxide	EPA Method 25C, Summa	2-3 L/min	GC
Temperature	Thermistor, variable resistor	Every second	HOBO® U12-013
Relative humidity	Electronic sensor	Every second	HOBO® U12-013

2.2.5 Carbon Dioxide by NDIR CEM

Carbon dioxide measurements were performed using LI-COR Biosciences LI-820 and LI-840 non-dispersive infrared (NDIR)-based CEMs mounted on the Flyer and scissor lift, respectively. The LI-CORs were using a 14 cm optical bench, giving them an analytical range of 0-2,000 ppm and 0-5,000 ppm for LI-820 and LI-840, respectively, with an accuracy specification of <2.5% of reading. The instruments were preceded by a filter for particulate matter removal before the optical lens. Signal averaging was set to 10 seconds per reading. The LI-COR Biosciences LI-820 and LI-840 CEM were equipped with programmable alarm outputs (trigger circuit), which turned on the semi-volatile blower and the PM-10 pump and opened the solenoid valve on the Summa canister. This alarm circuit was programmed to turn on at 410 and 400 ppm CO₂ for OB and OD, respectively, which was about 20-10 ppm above the ambient levels (390 ppm) of CO₂ at Tooele Army Depot. The lower level for OD was chosen to ensure sufficient sample volumes from the anticipated lower OD plume concentrations. At these CO₂ levels, the Flyer was deemed to be within the plume. The LI-COR Biosciences LI-820 and LI-840 NDIR-based CEMs were calibrated for CO₂ on a daily basis using a zero gas (100 % nitrogen), span gas (952 ppm CO₂ in nitrogen), and gases of intermediate CO₂ concentrations (400 and 650 ppm).

2.2.6 Summa Canister Sampling for VOCs and Carbon Dioxide

2.2.6.1 Sampling Method

Summa canisters (6 L capacity) were used for collection of volatile organic compounds (VOCs) via EPA Method TO-15 (USEPA 1999a). Canisters were obtained from a commercial laboratory (CAS) that could: (1) supply canisters with an electronic valve sampling system, (2) analyze for target analyte benzene (as well as other compounds) at low limits of detection, and (3) provide 24-hr turnaround time on analyses. The electronic valve sampling system was opened and closed by the CO₂ concentration trigger circuit at operator-set levels. The valve was followed by a frit filter in the stem of the Summa canister. The valves were designed by the firm to provide 30 s, 2 min, 5 min, and 10 min sampling durations.

Before deployment, the Summa canisters were checked at the USEPA laboratories for valve function (opening and closing) and combustion sampling. The Summa canister was placed inside an open burn test facility with a small biomass fire and allowed to sample at CO₂ levels exceeding 500 ppm. The canister was checked for the function of the electronic valve with the CO₂ trigger. The spent canister was sent for analysis and confirmed emission sampling and detection of naphthalene. In the field, a single electronic valve was used by transferring it from filled to empty containers after each sampling. A backup valve was used for the second half of the test program when one of the electronic connectors broke during preparation. Before each experiment, the Summa canister electronic valve functioning was checked to see if it opened and closed.

2.2.6.2 Analytical Method

The volatiles were analyzed using EPA Method TO-15 (USEPA 1999a) using selective ion monitoring (SIM) mode GC/MS. A 1 L aliquot was pulled from the Summa canister and analyzed. An internal spiking mixture containing bromochloromethane, chlorobenzene-d5, and

1,4-difluorobenzene at 10 ppmv each in humidified zero air was added to the sample or calibration standard. 500 μL of this mixture spiked into 500 mL of sample resulted in a concentration of 10 ppbv. The internal standard was introduced into the trap during the collection time for all calibration, blank, and sample analyses. The volume of internal standard spiking mixture added for each analysis was the same from run to run. A blank canister was analyzed daily. All surrogate standard recoveries were between 82 and 127 %, which was within the standard method criteria (70 and 130 %).

Each Summa canister sample was also analyzed for carbon dioxide by GC using EPA Method 25C (USEPA 1996), in which an aliquot of the collected Summa canister sample was injected into a sample loop equipped GC/FID. All surrogate standard recoveries were between 102 and 115 %, which was within the standard method criteria (94 and 137 %).

The data were background-corrected (BC) by subtracting the ambient air contribution to the sample:

$$\text{BC Analyte}_i = \text{Sample}_{\text{Analyte}_i} (\mu\text{g}/\text{m}^3) - \text{Ambient air}_{\text{Analyte}_i} (\mu\text{g}/\text{m}^3)$$

2.2.7 Semi-Volatile

2.2.7.1 Sampling Method

Semi-volatile organics, naphthalene, were sampled via EPA Method TO-13 (USEPA 1999b) using a PUF/XAD-2 resin/PUF sorbent. The pre-cleaned XAD-sorbent was further cleaned at the USEPA by solvent extraction with methylene chloride and drying with helium to minimize contamination of the media with the target analytes. This sorbent was delivered to the test site already mounted in a glass cartridge. The sorbent was prepared for sampling by removing it from its shipping container, removing the aluminum foil wrapping, and inserting it in a cartridge holder mounted on a MINIjammer brushless direct current (BLDC) blower (AMETEK). Semi-volatile sampling was performed using a BLDC low voltage blower for a nominal sampling rate of $0.25 \text{ m}^3/\text{min}$. The blower was controlled by the CEM CO_2 trigger circuit. Flow rate was measured by pressure differential across a calibrated venturi. All the venturis are carefully calculated and constructed constrictors made and calibrated at the USEPA shop. As used here, the venturi was mounted on the outlet of the semi-volatile sampler. A venturi has the property that fluid pressure through a constricted section of pipe is reduced. The fluid velocity must increase through the constriction to satisfy the equation of continuity, while its pressure must decrease due to conservation of energy. As such, a measurement of ΔP between the venturi's inlet and constricted diameter body measured this pressure drop, and that data was used to calculate flow rate. In practice, a calibration curve was developed from ΔP and actual flow measurements. The voltage equivalent to this pressure differential was recorded on the HOBO® external event logger. The USEPA Metrology Laboratory performed these measurements using the venturi's matched transducer and HOBO® with a Roots meter. Following sampling, the glass cartridge (sorbent) was removed from the Flyer, wrapped in clean aluminum foil to seal the ends, returned to its shipping container, labeled, and stored at 4°C until shipped to the laboratory. The

PUF/XAD sorbent method also allowed us to look for polycyclic aromatic hydrocarbons (PAHs) other than naphthalene.

2.2.7.2 Analytical Method

The semi-volatile PUF/XAD samples were prepared for analysis by solvent extraction using dichloromethane and then concentration by solvent evaporation. An internal standard, d8-naphthalene and others, was added to the sorbent before the sample was collected (Table 2-6). The surrogate recoveries were measured relative to the internal standards and are a measure of the sampling train collection efficiency. A deuterated recovery standard, D10-pyrene, was added before mass analysis. Samples were analyzed using full-scan mode. All surrogate standard recoveries were between 59 and 112 percent, which was within the standard method criteria (25 and 130 percent).

Table 2-6. PAH surrogates, composition and purpose

Spiking Solution	Analytes	Special Notes
PAHs - Internal Standards	D8-Naphthalene, D10-Acenaphthene, D10-Phenanthrene, D12-Chrysene, D12-Perylene	Added to sorbent before shipment to field
Recovery	D10-Pyrene	Added before mass analysis

Trip and field blanks were collected and analyzed. The trip blank was taken from the laboratory to the test site and returned to the laboratory unopened. The field blank was used for sampling ambient air to determine background concentrations. Both samples were analyzed for levels of target analytes and used to calculate the emission factor. The data were background-corrected (BC) according to:

$$\text{Ambient air Analyte}_i \text{ (ng/m}^3\text{)} = \frac{\text{Ambient air}_{\text{Analyte}_i} \text{ (ng/sandwich)} - \text{Trip blank}_{\text{Analyte}_i} \text{ (ng/sandwich)}}{\text{Ambient air Sampling volume (m}^3\text{)}}$$

$$\text{BC Analyte}_i = \frac{\text{Sample}_{\text{Analyte}_i} \text{ (ng/sandwich)} - \text{Trip blank}_{\text{Analyte}_i} \text{ (ng/sandwich)}}{\text{Sample Sampling volume volume (m}^3\text{)}} - \text{Ambient air}_{\text{Analyte}_i} \text{ (ng/m}^3\text{)}$$

2.2.8 Particulate Matter and Lead

2.2.8.1 Sampling Method

PM-10 sampling on the Flyer and scissor lift was performed using a 47 mm tared Teflon filter with a pore size of 2.0 µm.. The filters were shipped to the site pre-tared and mounted in sealed petri dishes. The filters were placed in PM-10 impactors and connected to the sampling pumps. PM-10 sampling was performed via an SKC Leland Legacy Sample pump with a constant air-flow of 10 L/min. The internal flow sensor measures flow directly and acts as a secondary standard to constantly maintain the set flow. The volume display was continually updated, based on corrected flow rate multiplied by sampling time. The display presented the pump serial number, pump software revision level, flow rate, volume, temperature, atmospheric pressure, time of day, run time, and pump status, i.e., it contained hold and run as well as setup information. The pump

was controlled by the CEM CO₂ trigger circuit. Following sampling, the impactors were disassembled and the filters were placed in same 47 mm petri dishes and labeled. The petri dishes were also wrapped with Teflon tape as further insurance against seals opening during preservation and shipment. The sealed petri dishes were placed in a reclosable bag pre-loaded with desiccant. The SKC Leland Legacy Sample pump was calibrated, before and after the sampling campaign, with a Gilibrator Air Flow Calibration System (Scientific Instruments), which is a primary standard airflow calibrator.

2.2.8.2 Analytical Methods

PM-10 was measured gravimetrically as the difference between final and tare masses for each filter. The weighing of the filters followed the procedures described in 40 CFR Part 50 (40 CFR Part 50, Appendix J, 1987). Calibration for determining mass of conditioned media was performed as described in Quality Assurance Guidance Document 2.12 (USEPA, 1998). The particulate matter collected on Teflon filters was also used to determine the lead concentration. EPA Compendium Method IO-3.3 (USEPA 1999c) specifies the analysis by energy dispersive x-ray fluorescence spectrometry (EDXRF). This method is compatible with particulate on filters, is quite sensitive for lead, and is non-destructive. This means that the particulate matter and substrate survive the analysis intact; and may be archived or analyzed by other methods.

The data were background-corrected according to:

$$BC PM_{10} = Sample_{PM_{10}} (\mu g/m^3) - Ambient\ air_{PM_{10}} (\mu g/m^3)$$

2.2.9 Sampling Time

Sample times for the Summa canister and particulate filter were not separately recorded. Sampling time for the Summa canister, semi-volatile sorbent, and PM-10 filter were all based on the same CEM CO₂ trigger circuit. They were, therefore, identical (up to the point where the Summa canister has been filled to ambient pressure, at which point it ceases to collect sample). Sample time was, therefore, based on the semi-volatile sampling blower where voltages from the venturi's differential pressure measurement were recorded on the HOBO® external event data logger. Sampling time was based on data logged onto the HOBO® U12-013. Each recorded event was time and date stamped, automatically updated with the computers date and time properties, which were set to local U.S. Mountain Time. The HOBO® maintains an internal time, which has a time accuracy of ± 1 min per month.

2.2.10 Calculation of Emission Factors

The CO₂ CEM data or Summa canisters were used to calculate a co-sampled carbon concentration, which permitted conversion of analyte concentrations to emission factors by the carbon mass balance method. In this method, the ratio of the sampled target analyte concentration to the total sampled carbon (represented by CO₂) is related back to the initial ordnance weight through knowledge of the carbon concentration/carbon fraction in the original ordnance and the assumption of 100% oxidation of the carbon. In all emission factors, the background concentration of the target analyte, determined from Flyer-based instruments and ground-based upwind instru-

ments, is subtracted from the measured amount. The carbon fraction was 30% and 37% for M1 and TNT, respectively (Table 2-2).

Emission factors were calculated according to (AP-42 1999).

$$EF_i = f_c \times \frac{Analyte_{ij}}{C_j}$$

Eq. 2-1

where:

- EF_i = Emission Factor for target analyte i (lb/lb NEW).
- f_c = mass fraction of carbon in the ordnance.
- $Analyte_{ij}$ = background-corrected concentration (lb analyte_i/cu ft) of the target analyte i collected from the volume element j of the plume.
- C_j = background-corrected concentration of carbon (lb C/cu ft) collected from volume element j of the plume (carbon calculated from CO₂ from either the CEM or the Summa canister).

2.3 Micropulse Light Detection and Ranging, Tapered Element Oscillating Microbalance, and Anemometer System

PM-10 mass emission factors were determined for OB of M1 propellant and OD of TNT with C-4 explosive. The experimental apparatus used to measure the emission factors consisted of an open path (OP) Micro-Pulse Light detection and ranging device (MPL) located on a positioner and operated in a temperature controlled trailer, two Tapered Element Oscillating Microbalances (TEOMs) located on a scissors lift, and two anemometers (Table 2-7, Yuen et al., 2010). A custom laser transmissometer was also deployed in the field but it did not work due to the failure of the data acquisition card that prevented storage of the signals determined by the laser transmissometer. Range resolved light extinction values measured with the MPL were used in the analyses in place of the proposed light extinction values measured by the laser transmissometer. This system mapped temporal and spatial optical properties of the plumes with the MPL, measured mass concentration of the PM-10 with the TEOMs, and measured wind speed and wind direction with the anemometers. Results from the MPL and TEOM measurements were integrated to provide one-dimensional (1-D) and two-dimensional (2-D) PM-10 concentration profiles along the cross sections of the plumes scanned by the MPL. The concentration profiles were then combined with results from the wind speed and wind direction measurements, the duration of each event, and the mass of energetic ignited to obtain PM-10 mass emission factors.

Table 2-7. Sampling and analysis methods.

Target Measurement	Sampling Method	Sampling Rate	Analysis
Range-resolved aerosol backscatter and extinction coefficient	OP-MPL mounted on a positioner	1 vertical scan/10 sec	Range resolved aerosol particle backscatter of light at 527 nm
PM-10 mass concentration	TEOM	0.5 Hz	Vibration of a crystal
Wind speed and wind direction	Two anemometers	1 Hz	Frequency of propeller and direction of anemometer

2.3.1 Micro-Pulse LIDAR (MPL) with Positioner and Temperature Controlled Trailer

The use of pulsed light to detect PM in the form of cloud droplets can be traced back to the 1930s (Bureau 1946). This type of detection was named as Light Detection and Ranging (LIDAR) (by Middleton and Spilhaus 1953). The invention of the laser during the 1960s allowed LIDAR technologies to develop rapidly (Wandinger 2005). In 1992, the Goddard Space Flight Center under the National Aeronautics and Space Administration (NASA) developed the first MPL, which featured eye-safe laser and noise-limited photon counting capabilities (Spinhirne 1993; Campbell et al. 2002). This version of the MPL gave rise to a commercially available MPL. MPL technology was also improved to increase the system's reliability (Campbell et al. 2002). Recently, MPLs have been used to study optical properties of clouds (Campbell et al. 2002; Shiobara, Yabuki, and Kobayashi 2003; Campbell and Sassen 2008; Cordoba-Jabonero et al. 2009) and aerosols (Campbell et al. 2002; Anderson et al. 2000; Welton et al. 2002; Voss et al. 2001). The primary commercial manufacturers of MPLs are Sigma Space Corporation¹ and Science and Engineering Services, Inc.²

The MPL used for this field campaign is an elastic backscatter LIDAR operated at a wavelength of 527 nm (Figure 2-7 and Table 2-8). This MPL was developed at NASA and manufactured by Sigma Space Corporation, MD. The MPL was mounted on a positioner (ORBIT Advanced Technologies, Model: AL-4011-1E with control system AL-1613-3J (Figure 2-7 and Table 2-9) to allow the MPL to scan vertically and horizontally. Backscatter data from the MPL were used to determine the horizontal and vertical light extinction profiles of the plumes along the line of sight of the MPL. The extinction profiles are measured from sets of 15 m, 30 m, or 75 m bins depending on the setting of the MPL.

¹ www.sigmaspace.com/sigma/micropulseLidar.php

² www.sesius.biz

Table 2-8. Micro-pulse LIDAR specifications.

Specification	Measure
Wavelength	527 nm
Laser Power	1.0 W
Output Energy	~ 8 μ J
Pulse Repetition Frequency	2.5 kHz
Transceiver Aperture	178 mm
Transceiver Field-of-View	~ 100 μ rad
Range Resolution	15 m, 30 m, 75 m
Maximum Range	60 km

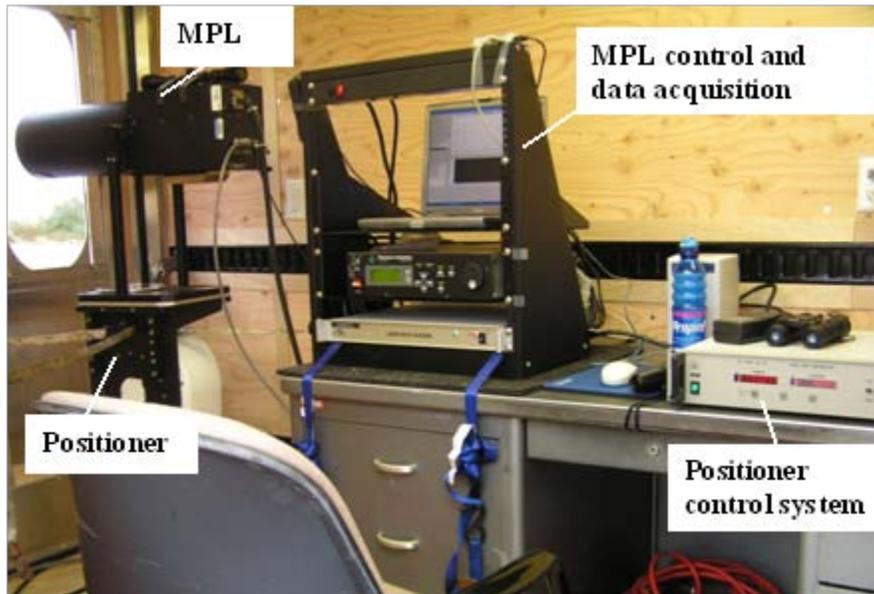


Figure 2-7. Micro-Pulse LIDAR located on the positioner in the temperature controlled trailer

Table 2-9. Positioner specifications

Specification	Measure	
Accuracy	Azimuth	$\pm 0.1^\circ$
	Elevation	$\pm 0.1^\circ$
Nominal Speed	Azimuth	$12^\circ/\text{s}$
	Elevation	$12^\circ/\text{s}$
Maximum Travel	Azimuth	$\pm 210^\circ$
	Elevation	-5° to 185°

This MPL was chosen for this field campaign because of the MPL's ability to complete range-resolved optical measurements of the plume's PM that is in contrast to path-integrated optical properties of the PM, that are measured by the laser transmissometer. This feature is important

due to the heterogeneity of the plume's PM-10 mass concentration. The MPL measures the amount of light that is backscattered by PM. The backscattered radiation is generated by the laser's pulsed light source and is measured as a function of distance from the MPL. The MPL determines the dust's mass concentration along the MPL's path by integrating the MPL's backscattered light signals with the optical and physical properties of the PM.

The MPL is an ORS technique that can provide continuous and non-intrusive measurements. The MPL has a 1-second integration time in collecting backscattering data, allowing optical property measurements at near real time conditions. Since the MPL uses only optical techniques, it does not need air-sampling devices, such as extractive point measurements, to measure radiation backscatter from PM. The MPL can be mounted on a positioner so that it can measure range resolved optical properties of plumes at elevated locations while the MPL is located on the ground.

Moreover, the MPL is designed to emit laser light at low pulse energies (i.e., $\sim 8 \mu\text{J}$), making it safe to human eyes. The MPL's laser can therefore be used to measure in all horizontal and vertical directions with minimal precautions.

2.3.2 Tapered Element Oscillating Microbalance (TEOM) Located on Scissor Lift

The TEOM was initially developed by Rupprecht & Patashnick (R&P model 1400) and is now available from Thermo Scientific (model 1405). Two TEOMs (Model 1400) sampled aerosol through an inlet at a gas flow rate of 16.7 L/min during the field campaign. The sample flow was then separated with 3 L/min passing to a Teflon-coated borosilicate glass filter. This filter vibrates on a hollow tapered element. The frequency of the vibrating filter is measured and recorded. As mass of PM on the filter increases, there is a commensurate reduction in the filter's frequency. The remaining 13.7 L/min is directed to an exhaust stream. PM mass is reported as cumulative mass collected and as mass concentration, corrected for local temperature and barometric pressure. The hydrophobic filter material with aerosol sampling at 50 °C (122 °F) (above ambient temperature) reduces artifacts due to the hygroscopic properties of the PM and filter. The TEOMs used PM-10 sampling inlets and were located on a scissor lift to raise the devices 10 m (32.8 ft) above the ground to more readily locate the TEOMs within the plumes (Figure 2-8). At times, the TEOMS were co-located based on DAC's recommendation to evaluate how well the results from the instruments agreed. The electronics for the TEOMs were located in custom enclosures to protect the devices during the OB and OD operations.



Figure 2-8. Two TEOMs and anemometer located on an elevated scissor lift (lift located closest to camera) at Tooele Army Depot, UT.

2.3.3 Anemometers

The two anemometers (R.M Young, model 05103V) measured the wind's speed and direction at 1-second intervals at two elevations by mounting the anemometers at the base and top of the scissor lift (Table 2-10, Figures 2-8 and 2-9). Wind speed is measured by magnetically induced AC voltage generated by the rotating blades. Wind direction is measured by a potentiometer. These data were then recorded with a National Instruments data acquisition system as analog voltage signals. The resulting speed and direction of the wind were then calculated by the calibration equations provided by the vendor.

Table 2-10. Anemometer's accuracy and detection limit.

Measurement Parameter	Accuracy	Detection Limit
Wind direction	$\pm 3^\circ$	1°
Wind speed	± 0.3 m/s or 1% of reading	1 m/s



Figure 2-9. One of the two anemometers used during the Tooele Army Depot field campaign.

2.3.4 Description of the Field Site and Location of the ORS Instrumentation for Open Burning and Open Detonation Tests

Figures 2-10 and 2-11, respectively, show the coordinates of the instrumentation deployed by University of Illinois for the open burning and the open detonation tests. The coordinates were determined with a handheld GPS (Garmin Models Nuvi 350 and eTrex Legend H) and recorded daily.

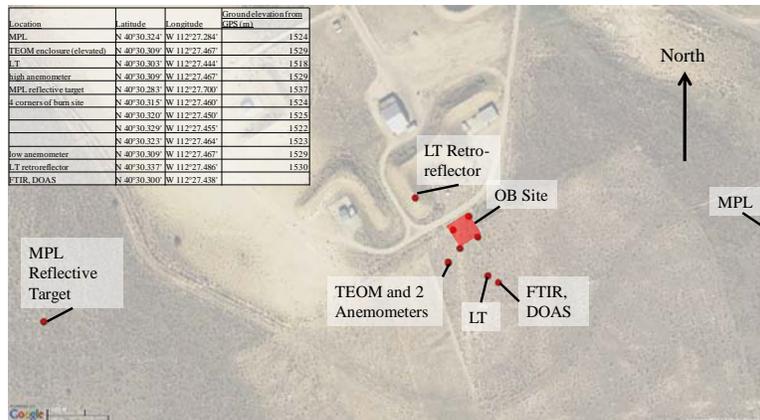


Figure 2-10. Schematic of open burning site including locations of equipment (18 March 2010).

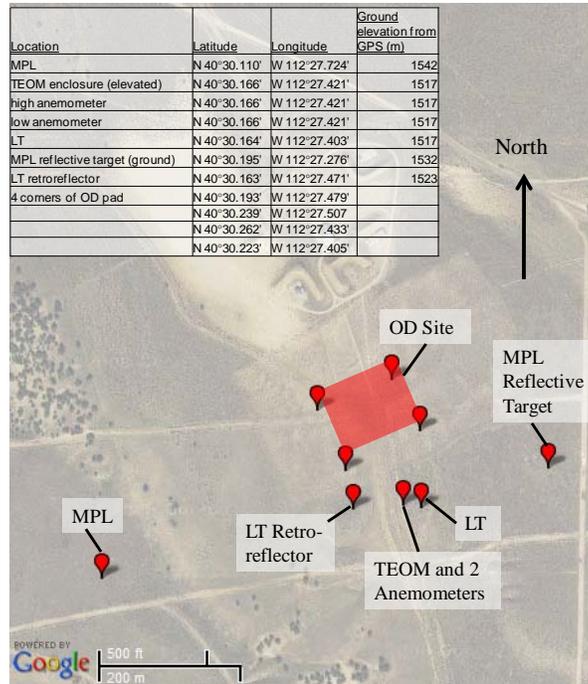


Figure 2-11. Schematic of open detonation site including locations of equipment (23 March 2010).

2.3.5 Optical Remote Sensing of PM, Measurement of Mass Concentration of PM-10, and Measurement of Wind Speed and Direction

Figure 2-12 shows the schematic describing the generation of plumes, the MPL, reflective target, TEOMs, scissor lift, and anemometers that were used to measure the spatial and temporal distribution of PM and the subsequent PM-10 emission factors for OB and OD events. The two TEOMs were located nominally 25 m away from the open burning sources and nominally 100 m away from the open detonation sources to the expected downwind direction. The expected downwind direction was determined by observation and the hourly wind direction forecast provided by National Oceanic and Atmospheric Administration (NOAA).³ A scissor lift (rented from Diamond Rental) lifted the two TEOMs so that they were 10 m above the ground.

³ Accessible through URL: <http://www.noaa.gov/wx.html>

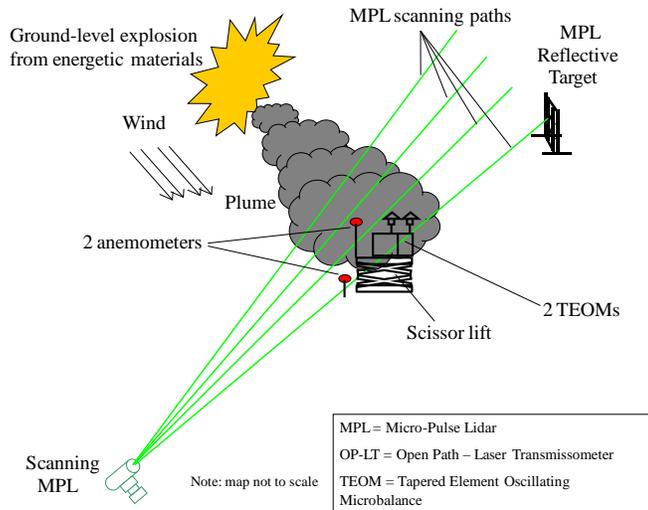


Figure 2-12. Schematic of open burning/open detonation operation and the ORS PM-10 measurement instrumentation.

The MPL and its reflective target were located such that the laser path between them was as perpendicular to the wind direction as possible. The MPL was mounted on a positioner such that the MPL’s laser could scan its measurement plane vertically from an elevation of 0 m to 100 m within the plumes. The locations of the TEOMs and retroreflector were matched with the MPL’s measurement path to co-locate them temporally and spatially.

Wind speed and wind direction were measured in the field every second by two anemometers located at 2.0 m and 11.7 m above the ground. The 2.0 m high anemometer was located on a 2.5 cm diameter pole located on a tripod on the ground. The 11.7 m high anemometer was also located on a 2.5 cm diameter pole that was mounted to the side of the elevated scissor lift. The horizontal distance between the two anemometers was < 5 m. A handheld compass was used to determine north so that the anemometers were pointing in consistent directions.

Wind speeds and directions were averaged per duration of each event. Wind speeds at 2.0 m and 11.7 m were first averaged separately, then the wind speeds were fitted versus elevation using a power-law relationship and regression constants were determined. The wind speed regression for each event was then used to describe the wind’s speed at any elevation of the plume:

$$u(z) = az^p \tag{Eq. 2-2}$$

where:

- a, p = regression constants
- z = height (m)
- u(z) = wind speed at height z (m/s)

Wind directions were determined relative to the normal direction of the MPL measurement plane. Then, cosines for each angle were then averaged. This average was used to determine the average wind speed that is normal to the MPL's measurement plane. The orientation of the MPL measurement plane was determined by the GPS coordinates of the MPL, TEOM, and the MPL's reflective target.

2.3.6 Methodology for Emission Factor Calculations

Figure 2-13 shows the overall schematic of the data processing for the MPL, TEOM, and anemometers to determine the PM-10 mass emission factors. Raw MPL photon counts were first corrected and normalized to determine normalized relative backscatter (NRB) values. These values were then used to determine 1-D light extinction profiles caused by the PM by inverting the LIDAR equation using the Beer-Lambert Law. 2-D extinction profiles were then determined by using multiple 1-D extinction profiles at select MPL positioner scan angles. Point mass concentration measurements by the TEOM were coupled with MPL extinction measurements to determine the mass extinction efficiency (MEE) for the plume's PM-10. Extinction profiles were then converted to PM-10 mass concentration profiles using MEE values. Finally the 2-D PM mass concentration profiles were integrated spatially and temporally with the wind speed and wind direction data to determine the mass of PM-10 emitted from the OB/OD event. The mass of PM-10 was then divided by the Net Explosive Weight (NEW) of the energetic material to determine the PM-10 mass emission factor.

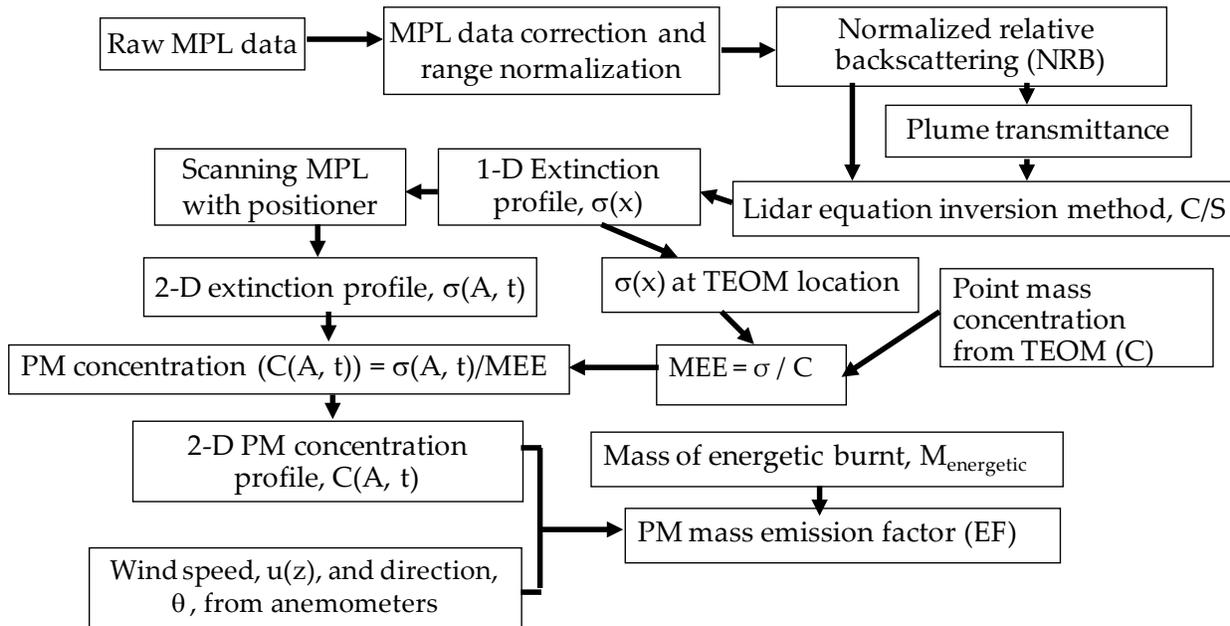


Figure 2-13. Schematic describing measurements and use of results to determine PM mass emission factor.

During this field campaign, select events were chosen to operate the positioner at one or two fixed angles. For select OD events, the positioner was operated at one fixed angle allowing the

MPL's laser to be directed co-linearly at the reflective target and next to the inlets of the TEOMs. For OB events, where the MPL, TEOMs, and reflective target did not readily form a collinear line of sight, the two fixed angle mode allowed the MPL's laser to be directed at only two angles where the reflective target and TEOMs were each located. Longer averaging times were achieved for each event during these measurement modes to determine averaged C/S values, where C is the LIDAR system constant and S is the extinction to backscatter ratio, and averaged MEE values. These two parameters are needed to determine the PM-10 mass concentration profiles and the resulting PM-10 emission factors. The averaged values for C/S and MEE are then available for use with events when the MPL characterized the entire plume's cross-sections, but the plumes were not detected by the TEOMs (to determine MEE values) or the plumes did not pass along the line of sight between the MPL and the reflective target (to determine C/S values). These events still provided emission factor results by utilizing the measured extinction profiles from the MPL, with the averaged C/S and MEE values, wind speed, wind direction, duration of the event, and the mass of energetic burned or detonated as described in Section 3.2.

2.3.6.1 Inversion of MPL Data To Obtain Extinction Profiles through Dust Plumes.

As previously mentioned, the MPL detects aerosol particles by emitting pulses of laser light into the atmosphere and then detecting the light that is backscattered by the PM. The raw LIDAR signal, $p(r)$, in photon counts/sec represents intensity of the received laser light that is backscattered by the PM at a distance of r . The objective of the MPL data calibration is to correct the raw LIDAR signal to obtain the NRB signal, which accounts for dark count, dead time, background noise, afterpulse artifact, overlap, and distance corrections.

Figure 2-14 shows a summary of the procedure to convert $p(r)$ values to NRB values. The dead time correction factor, $D[p(r)]$, corrects $p(r)$ values to account for the MPL's underestimation of the actual photon counts at high counting rates (e.g., > 5 Mcounts/sec). This correction is a function of the magnitude of the raw $p(r)$ values and is achieved by using a table of values provided by the manufacturer of the MPL.

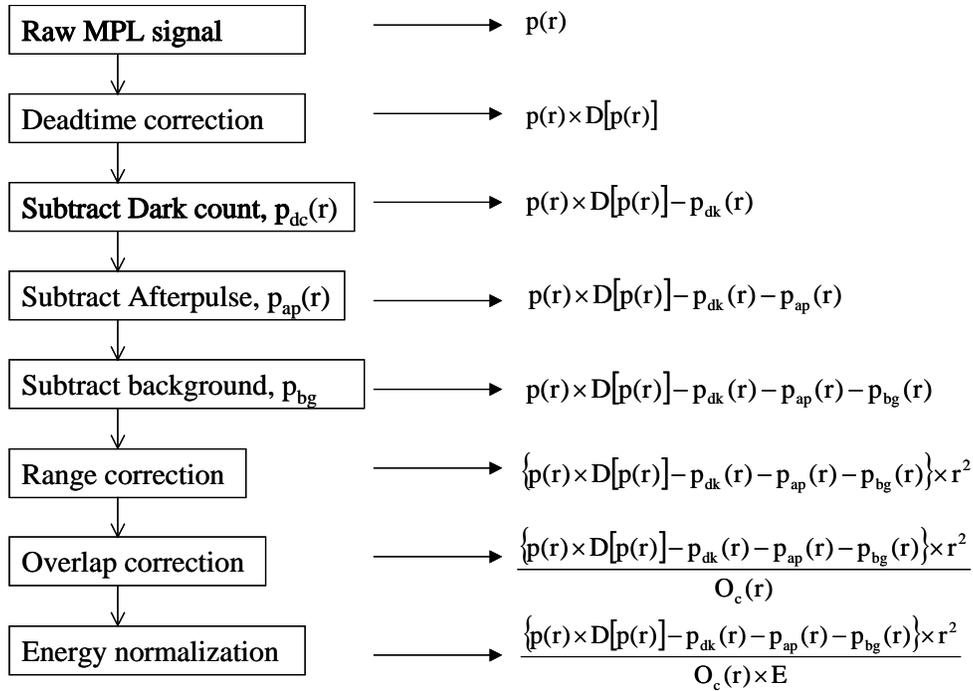


Figure 2-14. Methodology to convert MPL’s raw photon counts to NRB values.

The resulting $p(r)$ values are then corrected for dark counts ($p_{dc}[r]$) because the MPL’s photon counting module detects energy, as photon counts, even when the unit’s laser is off. Dark counts are measured when the laser is off, and its mean value is subtracted from the $p(r)$ values.

The resulting $p(r)$ values are then corrected with the afterpulse signal, $p_{ap}(r)$, which is caused by internal reflections of the laser light within the laser that saturate the detector diode at the beginning of the sampling period, and a small amount of leakage of photon count signal is detected for the remaining period of the pulse. Afterpulse signals are obtained by covering the outlet of the transceiver with the laser powered on, and the resulting photon counts are subtracted from the dark count corrected LIDAR data.

The MPL also detects background photon counts, p_{bg} , which are detected from background light, laser detector noise, and the remaining afterpulse at large distances away from the MPL. The value for p_{bg} is determined by recording the photon counts corresponding to a 40 km (25 mi) distance where no laser light remains to provide backscattered light. The signal is averaged between a distance of 40 and 55 km (25 and 34 mi), and is then subtracted from the afterpulse corrected LIDAR data. In this application, where the MPL points horizontally in daytime, further background correction is done by collecting backscatter data at each select scan angle before each event. These data are treated as background signals and are subtracted from each cycle of scans.

The background corrected LIDAR signal is then distance corrected due to divergence of the laser signal by multiplying the background corrected LIDAR signal by the square of the distance

where the LIDAR signal is detected. This signal is then modified with the overlap correction factor, $O_c(r)$, because the MPL has a narrow field of view for its receiver, $100 \mu\text{rad}$, that results in a compromised optical efficiency when detecting the backscattered laser light in near field. The field of view of the receiver cannot “observe” the entire laser beam in the near field until a distance where the more rapidly diverging field of view is able to cover the entire cross-section of the more slowly diverging laser beam ($\sim 50 \mu\text{rad}$) (Campbell et al. 2002). Finally, the overlap corrected LIDAR signals are energy normalized by dividing those values by the initial pulse energy of the laser (E) to provide the NRB signals:

$$\text{NRB}(r) = \{ (\rho(r) \times D[\rho(r)]) - \rho_{dc} - \rho_{bg} - \rho_{ap}(r) \} \times \frac{r^2}{E} \times \frac{1}{O_c(r)} \quad \text{Eq. 2-3}$$

The extinction of the LIDAR signal that is caused by the PM can now be described with known values of $\text{NRB}(r)$ and the “LIDAR equation” (Equation 2-3). The “LIDAR equation” relates $\text{NRB}(r)$ to the aerosol’s backscatter cross-section (β), transmittance of the laser’s light pulses (T) and a LIDAR system constant (C).

$$\text{NRB}(r) = \beta(r) \times (T^2(r)) \times C \quad \text{Eq. 2-4}$$

From Beer-Lambert Law, $T^2(r)$ is related to the aerosol’s extinction coefficient (σ) and distance (r) by:

$$T^2(r) = \exp\left[-2 \int_0^r \sigma(r') dr'\right] = \exp\left[-2S \int_0^r \beta(r') dr'\right] \quad \text{Eq. 2-5}$$

where S is the “LIDAR ratio” or the “extinction-to-backscatter ratio” and is defined as σ/β , and is determined by the optical properties of PM and the incident light’s wavelength. The analytical solution to the LIDAR equation was derived by (Fernald et al. 1972) and (Roy, Vallee, and Marcelin 1993) to determine the extinction profile from the NRB profile by:

$$\sigma(r) = \frac{\text{NRB}(r)}{C^* - 2 \int_0^r \text{NRB}(r') dr'} \quad \text{Eq. 2-6}$$

where C^* is defined as: $C^* \equiv C/S$.

The minimum resolution of the $\text{NRB}(r)$ signal from the MPL for this research is 15 m. Hence, the integral part in Equation 2-6 can be approximated by the summation:

$$\int_0^r \text{NRB}(r) dr \approx \sum_{i=1}^{r/15} [\text{NRB}(i) \times 15] \quad \text{Eq. 2-7}$$

where $i = 1, 2, \dots, r/15$.

Therefore, the extinction profile through a dust plume, which spreads over \tilde{N} bins that are each 15m (49 ft) wide, is determined from the discrete NRB(r) profile and C^* by Equation 2-7:

$$\sigma(n) = \frac{\text{NRB}(n)}{C^* - 2 \sum_{i=1}^n [\text{NRB}(i) \times 15]} \quad \text{Eq. 2-8}$$

where $n = 1, 2, \dots, \tilde{N}$.

The integral part in Equation 2-5 can also be approximated by Summation to determine the transmittance of the entire dust plume:

$$T = \exp \left[- \sum_{i=1}^{\tilde{N}} (\sigma(i) \times 15) \right] \quad \text{Eq. 2-9}$$

During the field campaign, a reflective target (and at select times the ground) was located behind each of the dust plumes. Therefore, the transmittance of laser light through the dust plumes can be determined from the reflective target's NRB signals before and after the dust passes through the MPL's optical path (Du et al. 2006):

$$T = \sqrt{\frac{\text{NRB}_t}{\text{NRB}_{t_0}}} \quad \text{Eq. 2-10}$$

where NRB_t is the NRB signal from the reflective target during a plume event and NRB_{t_0} is the NRB signal from the reflective target before the plume event.

Finally, the light extinction profile through a dust plume can be determined by solving a system of $(\tilde{N} + 1)$ equations with $\tilde{N} + 1$ unknowns (i.e., $\sigma_1, \sigma_2, \dots, \sigma_{\tilde{N}}$, and C^*):

$$\left\{ \begin{array}{l} \sigma(1) = \frac{\text{NRB}(1)}{C^* - 30\text{NRB}(1)} \\ \sigma(2) = \frac{\text{NRB}(2)}{C^* - 30(\text{NRB}(1) + \text{NRB}(2))} \\ \vdots \\ \sigma(\tilde{N}) = \frac{\text{NRB}(\tilde{N})}{C^* - 30(\text{NRB}(1) + \text{NRB}(2) + \dots + \text{NRB}(\tilde{N}))} \\ \sqrt{\frac{\text{NRB}_t}{\text{NRB}_{t_0}}} = \exp \left[- (\sigma(1) + \sigma(2) + \dots + \sigma(\tilde{N})) \cdot 15 \right] \end{array} \right. \quad \text{Eq. 2-11}$$

2.3.6.2 Determination of mass concentration profiles from light extinction profiles

The 1-D light extinction profiles were converted to 1-D PM mass concentration profiles by using the averaged MEE value determined with the PM-10 measurements by the TEOMs and the light extinction values measured with the MPL. Simultaneous PM-10 mass concentrations and light extinction values were determined for OB and OD plumes in the constant level scan mode when the MPL's light beam passed close to, but not directly on, the inlets of the TEOMs. The constant level scan mode was used to increase the time averaging of the measurements of the light extinction values and PM mass concentrations.

During the field campaign, data from the TEOM demonstrated step functions during each plume event and then stabilized after each event. Mass collected by the TEOM during each event was then used to determine MEE values. MEE is defined as σ/C , where σ is the extinction coefficient and C is mass concentration. MEE was determined with time averaged TEOM measured mass concentration data as described by:

$$\text{MEE} = \frac{F \int_{t_1}^{t_2} \sigma(\tau) d\tau}{m_{t_1-t_2}} \quad \text{Eq. 2-12}$$

where:

- MEE = mass extinction efficiency (m^2/g)
- t_1 = time before an event (sec)
- t_2 = time after an event (sec)
- $m_{t_1-t_2}$ = collected PM-10 mass by TEOM for an event (μg)
- F = TEOM sample flow rate (L/min)
- $\sigma(\tau)$ = extinction coefficients measured by MPL at the TEOM location at time τ (m^{-1}).

MEE is assumed constant spatially and temporally within a plume type for all events because MEE is a normalized particle property that depends on particle size distribution, density, and optical properties. Such approach, using MEE as an intensive property, is justified by results from previous field campaigns that determined mass scattering efficiencies and mass extinction efficiencies showing reasonably constant values for a particular type of source (i.e. ambient aerosol (Rood, M. J. et al., 1987, Shendrikar, A. D. and Steinmetz 2003, Chow, J. C. et al., 2006, and Upadhyay, J. K. et al. 2006) and fugitive dust emissions from mobile sources (Hashmonay, R. A. et al., 2009), respectively). In addition, results provided below demonstrate the relatively constant MEE values for OB tests and then OD tests. There is also a comparison of PM-10 emission factors results when using a constant MEE value when compared to using specific MEE values for a particular event, which also justify this assumption. MEEs calculated from events measured in constant scan mode were therefore first averaged for each type of activity (OB or OD) and then applied to the events in full 2-D scan mode.

Extinction profiles, $\sigma(A, t)$, were converted to mass concentration profiles, $C(A, t)$, by Equation 2-13:

$$C(A, t) = \frac{\sigma(A, t)}{MEE} \quad \text{Eq. 2-13}$$

2.3.6.3 Determination of PM-10 Mass Emission Factors

Emission factors were then determined by integrating all of the time dependent vertical 2-D PM-mass concentration profiles during each plume event with wind speeds and wind directions, and mass of energetic that was burned or detonated (Equation 2-13). This integration was completed by using a polar coordinate system to match the radial direction of the MPL scans. Wind speed was treated as a function of height (as previously described):

$$EF = \frac{\sum_{t=0}^T \left(\sum C(A, t) \Delta A \right) u(z) \cos \Theta}{M_{\text{energetic}}} \quad (\text{lb-PM-10/lb-NEW}) \quad \text{Eq. 2-14}$$

where,

- EF = emission factor (lb PM-10 / lb NEW)
- T = total time that the plume traveling across the MPL scan plane (sec)
- $C(A, t)$ = mass concentration of a point in vertical plane (A) at a time (t), measured by MPL system (mg/m^3)
- $u(z)$ = wind speed as a function of height (z), measured by two anemometers that are mounted at the two different heights (m/s). The power law was used to fit wind speed versus height in obtaining wind speed at other heights.
- Θ = wind direction relative to the perpendicular of the scan plane of the MPL system (degree)
- $M_{\text{energetic}}$ = mass of NEW (lb).

2.4 ORS for Gases

The combination of OP-FTIR and UV-DOAS sensors were deployed to determine the path-integrated concentrations (PICs) of the gaseous components of the plume. The OP-FTIR sensor is capable of detecting and measuring any gas-phase compound that is infrared active, which includes the majority of gaseous components. Since some important species have high detection limits due to interference by water vapor or CO_2 , UV-DOAS was included since it has very low detection limits for measuring benzene, nitric oxide, and sulfur dioxide. Another solar occultation FTIR was employed and tested. A passive FTIR uses radiation from the sun as an infrared source by aiming the FTIR telescope through the plume directly at the sun. If properly placed, the passive FTIR can assess the entire plume across a path between the instrument and the sun.

2.4.1 OP-FTIR

The OP-FTIR method is an EPA approved method (TO-16). All data collection, analysis, and QA/QC (i.e., N₂O system calibration and minimum detection limit determination) procedures were conducted according to the TO-16 method. The University of Washington ETG OP-FTIR instrument was deployed and spectra were examined for outlier absorption bands to identify any gaseous compound and perhaps unstable transitional PM species that may be present in the plume. All detected species were quantified. The majority of gas-phase compounds have infrared absorption bands. An upper limit on the PIC value for any important but undetected combustion product is determined from the standard error of the regression fit of the measured spectra to the calibrated reference spectra of the target species.

2.4.2 UV-DOAS

The Cerex open-path UV-DOAS is a bi-static, broadband, spectral absorption instrument designed to measure the concentration of various constituents in the open air along a path of up to approximately 100 to 200 m. The instrument is mounted on a tripod with data processing and control through a laptop computer. The Cerex instrument was deployed for the purpose of acquiring mainly benzene, NO, NO₂, naphthalene, and, SO₂ spectral data for post processing. Benzene for example is characterized by several sharp UV absorption peaks in the 250 nm region of the spectra. The spectra are unique and highly identifiable. Only NO for OB events was detected by the UV-DOAS which was also detected by the OP-FTIR.

2.4.3 ORS Time-Averaging Method

The ORS Time-Averaging Method is a post-measurement analysis method for determining long term concentration averages and detection limits. This was used on multiple events to lower detection limits, and can be applied to any ORS measurement technology that produces a set of response-signal (single-beam) spectra. The two present-day technologies that fit this category are OP-FTIR and UV-DOAS. All the absorbance spectra OB events in a single day were averaged to search and quantify the minimum detection limit (MDL) for monitored compound of interest. The same analysis was performed for the OD events in a single day.

2.4.4 Solar Occultation

For assessment from the ground of the entire vertical OB/OD gas plume, two passive FTIR systems (IMACC and MIDAC) used radiation from the sun as an infrared source by aiming the FTIR telescope through the plume directly at the sun. Solar occultation data was collected to support the OP-FTIR in the event of insufficient data capture primarily during the OD events. In order to be useful for the EF calculation procedure it is critical that the open path will be approximately in same plane as the MPL plane. Due to safety procedures, these two instruments were located very far away downwind from the MPL vertical plane. Although, plumes were monitored by the solar occultation line of sight, this information was not useful for EF calculations.

2.4.5 Description of the field site and location of the ORS gas instrumentation for Open Burning and Open Detonation Tests

The layouts of the instrumentation deployed by Environ for the OB and OD tests are provided in Figure 2-15 and Figure 2-16, respectively.



Figure 2-15. Schematic of open burning site including locations of equipment



Figure 2-16. Schematic of open detonation site including locations of equipment

The schematic describing the generation of plumes, the MPL, reflective target, TEOMs, scissor lift, the two OP instruments and anemometers that were used to measure the spatial and temporal distribution of PM and gases and the subsequent gases emission factors for open burning and open detonation events is provided in Figure 2-17.

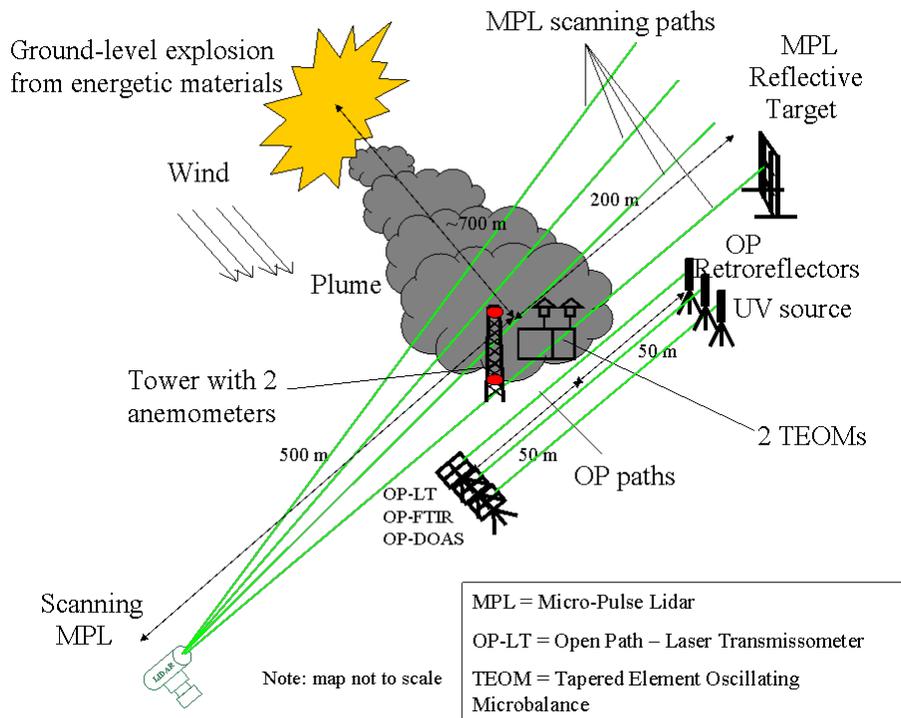


Figure 2-17. Schematic of open burning/open detonation operation and the ORS measurement instrumentation

2.4.6 Emission Factors Determination

The flux through the optical plane is determined from the product of the plume velocity and of the plane-integrated concentration determinations from the OP-FTIR and the Micro Pulse LIDAR (MPL) plume-geometry extrapolation. PIC determinations for each gas-phase compound are used to determine the plane-integrated concentrations, by calculating the extrapolation ratio, ER, of the MPL plane- integrated extinction at the limited area overlap with the open path (OP) measurement, $PI-EXT_{OP}$ and the MPL plane- integrated extinction for whole plume's cross-section (CS), $PI-EXT_{CS}$:

$$ER = \frac{PI - EXT_{OP}}{PI - ET_{CS}} \quad \text{Eq. 2-15}$$

Dividing the measured by the OP-FTIR gas concentration, C_{gas} , by ER provides the estimated gas plane-integrated concentration, PI-GC:

$$PI - GC = \frac{C_{gas}}{ER} \quad \text{Eq. 2-16}$$

The Flux calculation, F:

$$F(g/s) = PI - GC \times \bar{U} \times \cos \bar{\theta} \quad \text{Eq. 2-17}$$

Where

\bar{U} = is the vertical average of the wind speed function

$\bar{\theta}$ = vertical average of the wind direction relative to the perpendicular of the MPL scanning plane.

The Emission Factor, EF, is calculated by Equation 2-18:

$$EF(lb/lbNEW) = \frac{F \times T(s)}{454(g/lb) \times M_{energetic}(lb)} \quad \text{Eq. 2-18}$$

Where T is the duration of the event in seconds and $M_{energetic}$ is the NEW in lbs.

3. Results and Discussion

3.1 In-situ Balloon and Scissor Lift Sampling

3.1.1 CEMs

The Flyer successfully sampled emissions from the plumes in 85% of the 66 open burn pans of M1 propellant and 76% of the 37 open detonations of TNT, as determined by the number of times that the CO₂ concentration exceeded the trigger point of 410 ppm (OB) and 400 ppm (OD) (ambient air CO₂ concentration at Tooele Army Depot averaged 390 ppm). Table 3-1 lists these data and the average plume duration and CO₂ levels. The table reports the number of OB events and not the number of OB pans. These are not the same since multiple burn pans were ignited on some of the events.

Table 3-1. Flyer sampling summary.*

Matrix	No. OB/OD	Frequency of CO ₂ hits	Average ΔCO ₂ (ppm)	Average Sampling Time (seconds)
OB Flyer	60	85%	463	18
OD Flyer	37	76%	150	16
*ΔCO ₂ – background corrected CO ₂ .				

The scissor lift-mounted instruments sampled PM-10 in 41% and 3% (one hit) of the burns and detonations, respectively (Table 3-2), based on the same CO₂ trigger points as above.

Table 3-2. Scissor lift sampling summary.*

Matrix	No. OB/OD	Frequency of CO ₂ hits	Average ΔCO ₂ (ppm)	Average Sampling Time (seconds)
OB Scissor lift	54	43%	474	17
OD Scissor lift	32	3%	39	12 (one hit)
*ΔCO ₂ – background corrected CO ₂ .				

In each burn series there was about 1-2 minutes between each event and each detonation had about 2-30 minutes between events. Figures 3-1 and 3-2, respectively, show examples of the in-plume sampling time and time between each ignition as well as ambient air temperature for open burning and open detonation.

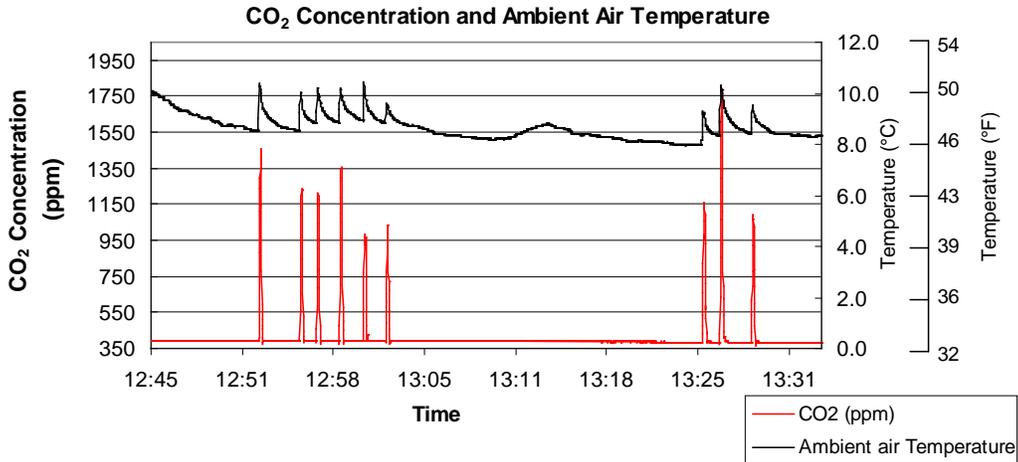


Figure 3-1. OB of M1 propellant. Each CO₂ peak representing one burn.

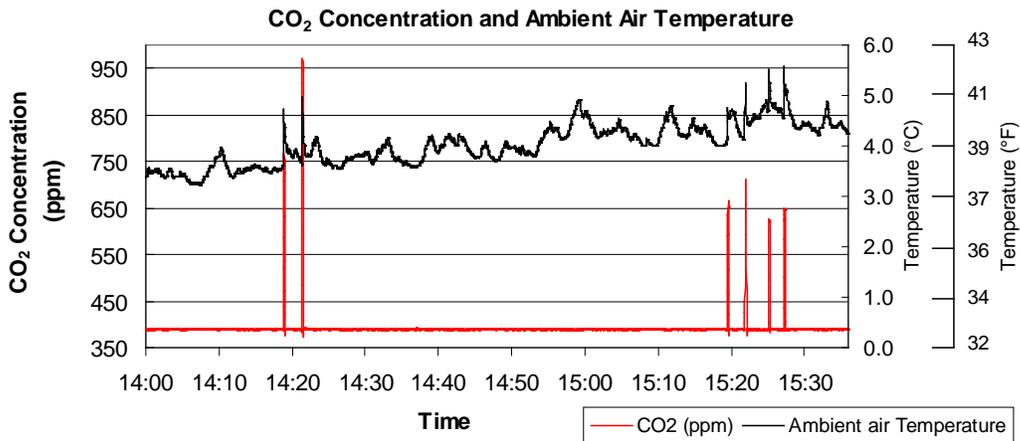


Figure 3-2. OD of TNT. Each CO₂ peak representing one detonation.

3.1.2 Emissions

3.1.2.1 Ambient Air Background Concentrations

Table 3-3 shows the measured ambient air background concentrations including CO₂ (390 ppm), naphthalene (0.014 μg/m³), benzene (0.46 μg/m³), and PM-10 (124 μg/m³). Summa canister CO₂ values were not used for background correction since the analytical method lacks the precision of the LI-COR CEM. The ambient air values were used to determine background-corrected emissions and emission factors.

Table 3-3. Ambient air background concentrations of target analytes.*

Matrix	Sampling Method and Sample Number	Sampling Time	Sampling Volume		Naphthalene	PM-10	Lead (Pb)	CO ₂	Benzene
		(min)	(m ³)	(cu ft)	(µg/m ³)	(mg/m ³)	(µg/m ³)	(ppm)	(µg/m ³)
Ambient air Background	XAD/PUF-01	72	16.2	572	0.007	DNA	DNA	389	DNA
	XAD/PUF-02	46	10.3	363	0.02	DNA	DNA	390	DNA
	PM-10-01	446	0.46	16.2	DNA	0.12	NA	390	DNA
	Summa canister -01	5	0.006	0.21	DNA	DNA	DNA	420	0.47
	Summa canister -02	30	0.006	0.21	DNA	DNA	DNA	400	0.44

* DNA - does not apply
 NA – not analyzed
 Method reporting limits: PM-10 1 µg (all PM-10 results >50 ug/filter)
 For Naphthalene, see Table 3-5,
 Benzene 0.17 µg/m³
 CO₂ 5 ppm (Summa canister).

3.1.2.2 Semi-Volatile Organic Compounds, PM-10, and Lead

Due to the short sampling duration of each burn/detonation, multiple events were used to create a single, composite sample for both semi-volatile (XAD/PUF) and PM-10. These single samples were created by reusing the same sorbent media or filter during multiple events. Two semi-volatile composite samples were collected for both OB and OD during the test campaign using the Flyer (Table 3-4). In addition, one and two PM-10 samples were collected for the burn and detonation tests, respectively.

Table 3-4. Background-corrected emission levels of CO₂, Naphthalene, PM-10, and Lead.*

Matrix	Sampling Method and Sample Number	Total Sampling Time	Total Sampling Volume		ΔNaphthalene	ΔPM-10	Lead (Pb)	ΔCO ₂	ΔCarbon Content	
		(s)	(m ³)	(cu ft)	(µg/m ³)	(mg/m ³)	(µg/m ³)	(ppm)	(g)	(lb)
OB Flyer	XAD/PUF-01	431	1.63	57.6	0.082	DNA	DNA	398	0.38	8.4E-04
	XAD/PUF-02	311	1.05	37.1	0.085	DNA	DNA	442	0.28	6.2E-04
	PM-10-01	802	0.13	4.7	DNA	4.9	0.0037	463	0.035	7.7E-05
OD Flyer	XAD/PUF-01	179	0.66	23.3	1.1	DNA	DNA	104	0.038	8.4E-05
	XAD/PUF-02	349	1.2	42.2	2.1	DNA	DNA	147	0.10	2.2E-04
	PM-10-01	305	0.051	1.8	DNA	29	NA	120	0.003	6.6E-06
	PM-10-02	171	0.029	1.0	DNA	27	NA	201	0.003	6.6E-06

* DNA – does not apply
 NA – not analyzed.
 Method reporting limits: PM-10 1 µg (all PM-10 results >50 ug/filter)
 For Naphthalene, see Table 3-5
 Lead 0.00014 µg/m³.

Analysis of the PUF/XAD sorbent made it possible to look for other non-target PAHs other than naphthalene. Table 3-5 shows these concentrations, which were primarily detected for the OD events.

Table 3-5. PAH concentrations, background corrected.*

Compound	OB XAD/PUF-01	OB XAD/PUF-02	OD XAD/PUF-01	OD XAD/PUF-02	Ambient Air Background
	(ng/m ³)				
Napthalene	82	85	1070	2150	13
Acenaphthylene	6.9 [‡]	14 [‡]	45 [‡]	141	0.80 [‡]
Fluorene	5.7 [‡]	BDL	30 [‡]	79	0.40 [‡]
Phenanthrene	BDL	BDL	76	296	BDL
Fluoranthene	BDL	BDL	52 [‡]	116	0.93 [‡]
Pyrene	BDL	BDL	72	158	1.6 [‡]
Benzo(a)anthracene	BDL	BDL	10 [‡]	19 [‡]	1.4 [‡]
Chrysene	BDL	BDL	12 [‡]	20 [‡]	3.4
Benzo(b)fluoranthene	BDL	BDL	BDL	16 [‡]	5.3
Benzo(k)fluoranthene	BDL	BDL	BDL	14 [‡]	2.9 [‡]
Benzo(a)pyrene	BDL	BDL	BDL	16 [‡]	2.6 [‡]
Indeno(1,2,3-cd)pyrene	BDL	BDL	BDL	7.8 [‡]	2.6 [‡]
Benzo(ghi)perylene	BDL	BDL	BDL	24 [‡]	3.1
MRL (ng/m ³)	31	48	75	42	3.1

* Detectable limits at least 3 times the signal to noise ratio.
MRL – method reporting limit, lowest point on calibration curve.
BDL – below detection limit, either never detected or if detected never detected above the background limit.
‡ Lower than method reporting limit before background correction.

One PM-10 composite sample was collected in each of the burn and detonation series using the scissor lift (Table 3-6).

Table 3-6. Background-corrected emission levels of CO₂, PM-10, and Lead, scissor lift sampling.*

Matrix	Sampling Time	Sampling Volume		ΔPM-10	Lead (Pb)	ΔCO ₂	ΔCarbon content	
	(s)	(m ³)	(cu ft)	(mg/m ³)	(μg/m ³)	(ppm)	(g)	(lb)
OB Scissor lift	358	0.060	2.1	6.8	NA	474	0.016	3.5E-05
OD Scissor lift	12	0.002	0.07	55	NA	39	4E-05	8.8E-08

* NA – not analyzed. Method reporting limit: PM-10 1 μg (all PM-10 results >50 ug/filter).

3.1.2.3 VOCs and CO₂ from Summa Canisters

The short duration of the Flyer in the plume precluded use of all but the 30 s sampling time Summa canister. The short plume residence times for the Flyer meant that multiple plume samples were necessary to fill the canister. The Summa canister from the first series of OB tests was

sent to the commercial laboratory for fast turnaround analysis while researchers were still in the field sampling. The analysis reported high levels of CO₂ (2140 ppm), which matched well with the values recorded by the LI-COR CEM monitor on the Flyer. The report also showed detectable and reasonable levels of benzene (34 µg/m³), which confirms this Summa canister sampling method and procedures. Subsequent results received by the commercial laboratory after the sampling program had finished showed much lower values of CO₂ and target VOCs. In five out of six OD Summa canisters the CO₂ levels were below the CO₂ trigger setpoint of 400 ppm or at, or below, ambient CO₂ concentrations. Further, these values did not agree with LI-COR CEM values through the plume. The Summa canister, its electronic valve, and frit were returned to the USEPA for testing in the metrology laboratory. Two problems were found that appear to have compromised all of the low-CO₂ Summa canister results. First, the valve system set for a 30 seconds sampling really produced an apparent sampling time of 120-180 seconds. Second, and most significant, the valve system was found to leak intermittently, resulting in a fill time of about 60 min. This suggests that as soon as the manual turn valve on the Summa canister was opened just before balloon launch, the system could have started sampling ambient air. As the pre-sampling wait period was approximately 30 to 90 minutes, the Summa canister would have had plenty of time to complete sampling before the OB/OD event. The system may also have not started leaking until after the first valve opening, where an incomplete valve seal would have allowed additional post-event ambient air to complete the Summa canister volume. These findings suggested that the poor valve seal could have significantly diluted the Summa canister VOC analytes. The apparent success of at least the first Summa canister suggests that the method works well, but requires different valves and pre-sampling quality assurance procedures. These hardware and procedural modifications are underway. Table 3-7 lists the background corrected CO₂ and benzene concentrations for Summa canisters with a CO₂ value above the set trigger point of 410 and 400 ppm for open burns and open detonations, respectively. The CEM CO₂ background concentration (390 ppm) was used to calculate the ΔCO₂ concentration in the plume for the Summa canisters results. Two full scan GC analyses of OB Summa cans resulted in elevated concentrations of toluene and ethylbenzene (not shown).

Table 3-7. Background-corrected benzene and CO₂ concentrations from Summa canisters.*

Matrix	Sampling Date and Sample Number	ΔCO ₂ (ppm)	ΔBenzene (μg/m ³)
OB Flyer	031210-01	1750	34
	031510-02	310	2.8
	031610-03	1010	4.4
	031610-04	270	1.7
	031710-06	550	3.0
	031710-07	100	1.0
	031810-08	150	1.2
	031810-09	90	0.29
	031810-10	130	0.93
	031810-11	160	1.5
OD Flyer	032010-02	20	6.3
Method reporting limits: Benzene 0.17 μg/m ³ , CO ₂ 5 ppm.			

3.1.2.4 Background Correction

The PUF/XAD-derived emissions and emission factors were calculated with corrections for contamination of the sorbent media itself as well as for ambient air background levels of the target analyte. The naphthalene concentration in the PUF/XAD sorbent after sampling was 3 times and >12 times higher for OB and OD, respectively, than the naphthalene contamination in each PUF/XAD sorbent before sampling. The Summa canister benzene values were 1-72 times and 14 times higher for OB and OD, respectively than in the ambient air. The PM-10 ambient air concentration was only 2.5% of the PM-10 sampled from OB and OD.

3.1.3 Emission Factors

Emission factors were calculated using both the Summa canister values of CO₂ (for benzene) and the CEM CO₂ values (for naphthalene, PM-10, and Pb) (Table 3-8). Table 3-8 lists these emission factors alongside those derived from previous open test range work of M1 propellant and TNT for comparison.

Table 3-8. Emission factors derived from this study and previous open test range work of M1 propellant and TNT (existing).*

Compound		Matrix			
		OB M1		OD TNT	
		EF	RSD/RPD	EF	RSD/RPD
Benzene (lb/lb C)	Existing	1.4E-05	140%	2.6E-04	65%
	Flyer	1.6E-05	54%	7.3E-04	DNA
Naphthalene (lb/lb NEW)	Existing	1.9E-08	362% [‡]	1.3E-06	171% [‡]
	Flyer	1.0E-07	9%	8.1E-06	31%
PM-10 (lb/lb NEW)	Existing	6.9E-03	41%	7.2	47%
	Flyer	5.7E-03	DNA	0.13	54%
	Scissor Lift	7.7E-03	DNA	0.97	DNA
Pb (lb/lb NEW)	Existing	NS	DNA	NS	DNA
	Flyer	4.3E-09	DNA	NS	DNA

NS – not sampled. BDL – below detection limit, either never detected or if detected never detected above the background limit.
DNA – does not apply.
RSD – relative standard deviation.
RPD – relative percent difference. lb/lb C – pound per pound carbon. lb/lb NEW – pound per pound net explosive weight. This EF derived from: Benzene – Summa canister; Naphthalene (XAD/PUF) – CEM; PM-10 – CEM; Pb – CEM.
No RSD values for each energetic were found in Chapter 16 (AP-42 2009) instead the RSD for all energetics from open test range was noted here.
[‡] RSD from EP category “SVOCs Not In Energetics” (AP-42 2009)

The naphthalene value here is about five times higher than the published value. However, the method used to determine the published value was based solely on an analysis of the filter catch. Even for ambient air methods (USEPA 1999b), significant loss of lighter semi-volatile compounds is expected without a post-filter sorbent for compounds in the range of naphthalene’s vapor pressure (USEPA 1996). For combustion sources, these losses may be even more significant. This study used XAD-2 resin as the primary sorbent media of semi-volatile compounds to minimize compound loss, a strategy confirmed by good pre-spiked recovery values.

The benzene EF value here for OB is very close to the existing EF value. For OD, the benzene EF value here is about three times higher than the existing data, however, the lack of precision of the Summa canister CO₂ values negates this difference.

Table 3-8 also lists PM-10 and Pb emission factors, which are based on CEM CO₂ values. The PM-10 values from OB sampled from the flyer and the scissor lift were both within the RSD of the published value. The PM-10 values from OD were about 50 times lower than the published data for OD of TNT. However, the published data have a quality rating of D (in a rating system from A to D) due to the following reasons according to Chapter 16 in AP 42 (2009) calculated from one single plume volume, powdery soil at the test site, deposited particles re-entrained from

the sampling probe, and wetness of soil entrained a higher quantity of particles into the plume. By comparison, the published BangBox® EF is 0.073 (AP-42 2009), which emphasizes that the PM-10 values depend on detonation surfaces.

Table 3-9 lists PAH emission factors other than naphthalene derived from this study and previous open test range work. The PAH concentration was at least four times higher than the background concentration (XAD contamination and ambient air concentrations). The pyrene value here is about 5 times higher than the existing EF, but this may also be due to difference in the sampling methods, i.e., only a filter was used in previous work compared to PUF/XAD sorbent used in this study.

Table 3-9. PAH emission factors for OD of TNT Derived from this study and previous open test range work (existing), in lb/lb NEW.*

Compound	OD	
	Flyer	Existing
Acenaphthylene	4.5E-07	ND
Fluorene	2.7E-07	ND
Phenanthrene	8.9E-07	BDL
Fluoranthene	4.2E-07	ND
Pyrene	5.8E-07	1.1E-07
Benzo(a)anthracene	7.3E-08	5.0E-08
Chrysene	8.0E-08	ND
Benzo(b)fluoranthene	6.8E-08	ND
Benzo(k)fluoranthene	6.0E-08	ND
Benzo(a)pyrene	7.1E-08	BDL
Indeno(1,2,3-cd)pyrene	3.4E-08	ND
Benzo(ghi)perylene	1.1E-07	ND
*ND- no data. BDL – below detection limit, either never detected or if detected never detected above the background limit. Method reporting limit for Flyer data see Table 2-2. lb/lb NEW – pound per pound net explosive weight.		

3.2 Micropulse Light Detection and Ranging, Tapered Element Oscillating Microbalance, and Anemometer System

Table 3-10 lists the overall description of the dates of the open burning and open detonation tests, number of tests during each day when UIUC performed field campaign measurements, and successful measurements for the MPL, C/S, TEOM, USEPA’s co-located measurements at the TEOMs, and simultaneous MPL, TEOM, and co-located USEPA measurements. Successful measurements are categorized as follows: 1) The MPL scanned the entire plumes’ cross-sections (in contrast to operating the MPL at one angle to determine MEE and C/S values with longer averaging times or if the plume’s duration was too short for adequate characterization); 2) The MPL measured the backscatter signals from the reflective target with each of the plumes located

between the MPL and the reflective target; and 3) The plume passed through the location of the TEOM samplers. The EPA's scissor lift-mounted instruments were not operating on the first day of OD testing (19 March 2010) and the last day of OB testing (25 March 2010). The TEOMs also required repairs resulting in replacement of a vibrating crystal and modification of their data acquisition system during the first two days of OB sampling (15 and 16 March 2010).

Table 3-10. Description of test dates for open burning and open detonation tests and percentage of successful tests.*

Date	Type of Test	Total Number of Tests	"Successful Measurements"					
			1) MPL Plume Profile	2) MPL C/S	3) TEOM	Simultaneous MPL and TEOM	EPA at TEOM	Simultaneous MPL, TEOM, and EPA
15-Mar	OB	5	0	5	NS	0	0	0
16-Mar	OB	10	5	5	NS	0	1	0
17-Mar	OB	17	17	17	0	0	7	0
18-Mar	OB	17	13	17	11	11	13	9
25-Mar	OB	8	6	8	1	1	NS	0
"Successful" OB (%)			72	91	21	21	43	16
19-Mar	OD	5	5	5	4	4	NS	0
20-Mar	OD	9	4	6	0	0	0	0
22-Mar	OD	10	2	10	10	5	0	0
23-Mar	OD	13	13	13	8	8	1	0
24-Mar	OD	7	5	7	5	4	NS	0
"Successful" OD (%)			66	93	61	48	3	0
*NS - Not Sampled								

Determination of PM-10 emission factors with ORS focused on 18 March 2010 for open burning tests and 23 March 2010 for open detonation tests due to the high success rate of measurements that occurred during those days. Tables 3-11 and 3-12, respectively show measured wind speeds and their dependence on height for 18 and 23 March 2010 (USEPA 1999c; AP-42 2009).

Table 3-11. Wind speed characterization for the open burning tests (18 March 2010).

Open Burning Event Number	Mean Wind Speed @ 2 m (m/s)	Standard Deviation of Wind Speed @ 2 m (m/s)	Mean Wind Speed @ 11.7 m (m/s)	Standard Deviation of Wind Speed @ 11.7m (m/s)	Constant (a) in Power Law Equation	Exponent (p) in Power Law Equation
1	2.49	0.12	2.56	0.11	2.45	0.02
2	3.03	0.62	3.76	0.36	2.69	0.14
3	2.57	0.28	2.38	0.44	2.66	-0.05
4	3.37	0.16	3.80	0.11	3.22	0.07
5	3.05	0.48	3.25	0.46	2.96	0.04
6	1.52	0.15	2.89	0.16	1.18	0.37
7	2.24	0.26	2.61	0.31	2.03	0.10
8	1.72	0.31	2.10	0.33	1.59	0.11
9	3.48	0.12	3.95	0.18	3.31	0.07
10	4.21	0.08	4.31	0.33	4.16	0.01
11	3.22	0.09	3.35	0.61	3.15	0.02
12	3.20	0.22	3.87	0.55	2.99	0.10
13	3.97	0.36	4.99	0.25	3.58	0.13
14	3.99	0.11	4.48	0.04	3.81	0.07
15	4.05	0.20	5.18	0.16	3.67	0.14
16	2.88	0.09	4.12	0.26	2.50	0.20
17	3.02	0.13	3.93	0.27	2.72	0.15

Table 3-12. Wind speed characterization for the open detonation tests (23 March 2010).

Open Detonation Event Number	Mean Wind Speed @ 2 m (m/s)	Standard Deviation of Wind Speed @ 2 m (m/s)	Mean Wind Speed @ 11.7 m (m/s)	Standard Deviation of Wind Speed @ 11.7m (m/s)	Constant (a) in Power Law Equation	Exponent (p) in Power Law Equation
1	3.25	0.14	5.22	0.20	2.69	0.27
2	4.08	0.43	5.91	0.41	3.51	0.21
3	3.69	0.31	5.52	0.47	3.15	0.23
4	3.62	0.27	5.32	0.37	3.11	0.22
5	3.80	0.31	6.10	0.24	3.13	0.27
6	5.11	0.44	7.03	0.49	4.50	0.18
7	3.88	0.33	5.41	0.17	3.36	0.19
8	4.97	0.51	8.26	0.85	4.06	0.29
9	5.10	0.21	7.54	0.25	4.36	0.22
10	4.68	0.89	7.60	0.73	3.78	0.28
11	5.44	0.22	8.45	0.57	4.58	0.25
12	4.69	0.17	7.89	0.31	3.82	0.29
13	5.51	1.01	8.18	1.03	4.64	0.23

Tables 3-13 and 3-14, respectively, list the averaged $\cos(\theta)$ values for wind directions relative to the measurement plane of the MPL on 18 and 23 March 2010. For example, the values of $\cos(\theta)$ describe if the wind direction was perpendicular to the MPL's measurement plane with a value of 1 and parallel to the MPL's measurement plane with a value of 0. The average \pm standard deviation values for $\cos(\theta)$ are 0.85 ± 0.10 and 0.95 ± 0.03 for 18 and 23 March 2010, respectively, indicating that the plume traveled quite close to the normal direction of the MPL's measurement plane.

Table 3-13. Average wind direction compared to measurement plane of the MPL for open burning events (18 March 2010).

Open Burning Event Number	Average $\cos(\theta)$ Values at 11.7 m and 2m above Ground Level
1	0.92
2	0.88
3	0.93
4	0.94
5	0.93
6	0.63
7	0.71
8	0.64
9	0.83
10	0.91
11	0.88
12	0.88
13	0.80
14	0.88
15	0.91
16	0.92
17	0.93
Average	0.85
Standard Deviation	0.1

Table 3-14. Average wind direction compared to measurement plane of the MPL for open detonation events (23 March 2010).

Open Detonation Event Number	Average $\cos(\theta)$ Values at 11.7 m and 2m above Ground Level
1	0.93
2	0.94
3	0.99
4	0.98
5	0.89
6	0.92

Open Detonation Event Number	Average $\cos(\theta)$ Values at 11.7 m and 2m above Ground Level
7	0.97
8	0.97
9	0.98
10	0.91
11	0.97
12	0.97
13	0.97
Average	0.95
Standard Deviation	0.03

As suggested by DAC, the two TEOMs were co-located on the scissors lift with both of them operating with PM-10 inlets. Figure 3-3 shows real-time measured PM mass values for OD tests during 22 March 2010, indicating strong agreement between the PM measurements made by the two TEOMs.

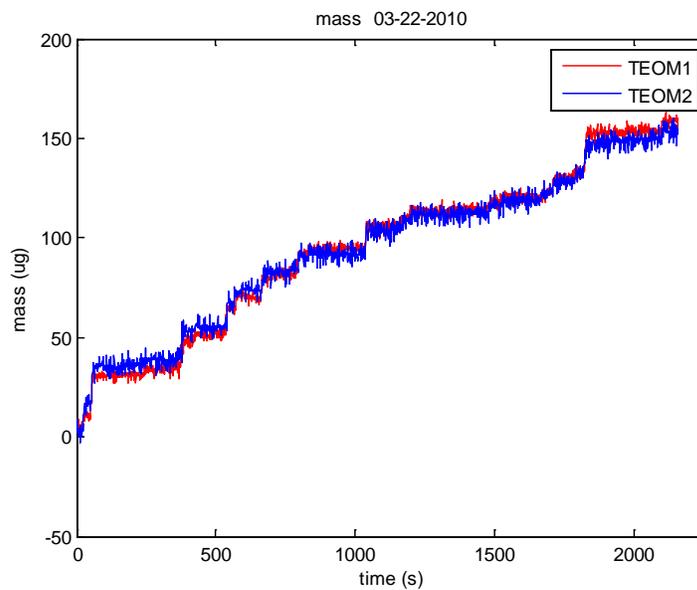


Figure 3-3. Comparison of TEOM PM-10 mass collected versus time for multiple OD Events and two co-located TEOMs.

Figure 3-4 shows and Table 3-15 lists mass concentration values of PM-10 measured by both TEOMs for OD events on 22 March 2010. Percent differences in mass concentrations ranged from -19% to +18% with an overall average difference of 4%.

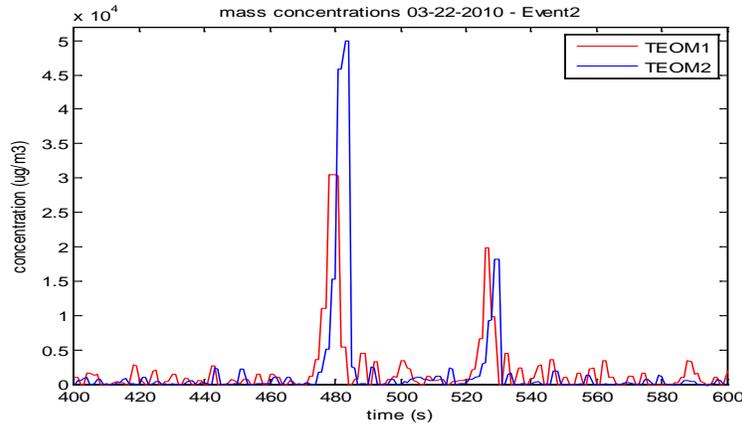


Figure 3-4. Comparison of TEOM PM-10 mass concentration versus time for multiple OD events and two co-located TEOMs.

Table 3-15. Comparison of measured PM-10 values for two co-located TEOMs.

OD Event Number 22 March 2010	Mean PM-10 TEOM ₁ (µg/m ³)	Mean PM-10 TEOM ₂ (µg/m ³)	Difference between TEOM ₁ and TEOM ₂ (%)
1	4,035	4,962	-19
2	3,225	3,454	-7
3	4,950	4,507	10
4	3,574	3,021	18
5	2,709	1,546	75
6	2,613	2,423	8
7	1,340	1,189	13
8	2,797	2,708	3
9	5,647	5,950	-5
10	1,840	1,853	-1
Overall Mean Values	3,273	3,161	4

Figure 3-5 shows a plot of C/S values versus maximum normalized relative backscatter (NRB) values of an open detonation event when the MPL was kept at a constant angle. C is the LIDAR system constant and S is the extinction to backscatter ratio. C/S values are compared when using the reflective target and nearby ground. Maximum NRB values are used for this initial test to indicate if the plume was detected between the MPL and the reflective target/ground. C/S values for the surfaces converge to a similar value as the NRB value approaches 40. It may be possible to use such response when C/S values are not available for a particular test.

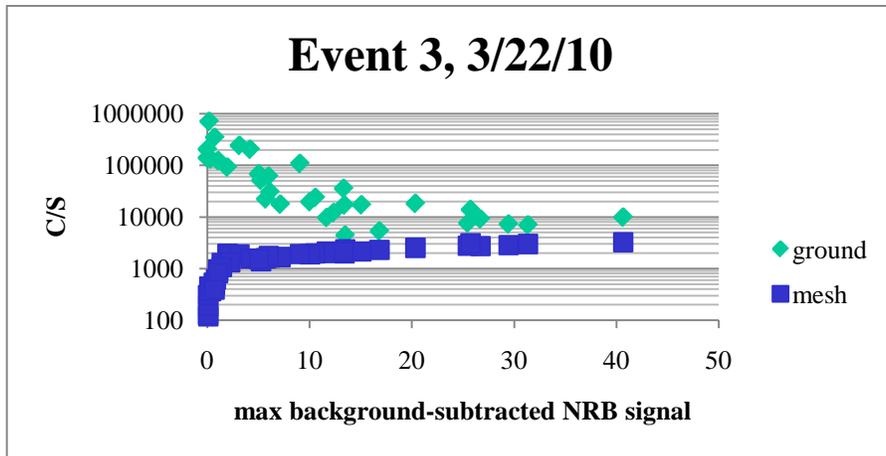


Figure 3-5. Typical dependence of C/S value on maximum NRB Value.

Figure 3-6 shows the temporal variation of the 2-D light extinction profiles for an open detonation event. At the sampling plane, the plume height reached 80 m, with a plume width up to 70 m, and a light extinction coefficient of 0.03 m^{-1} .

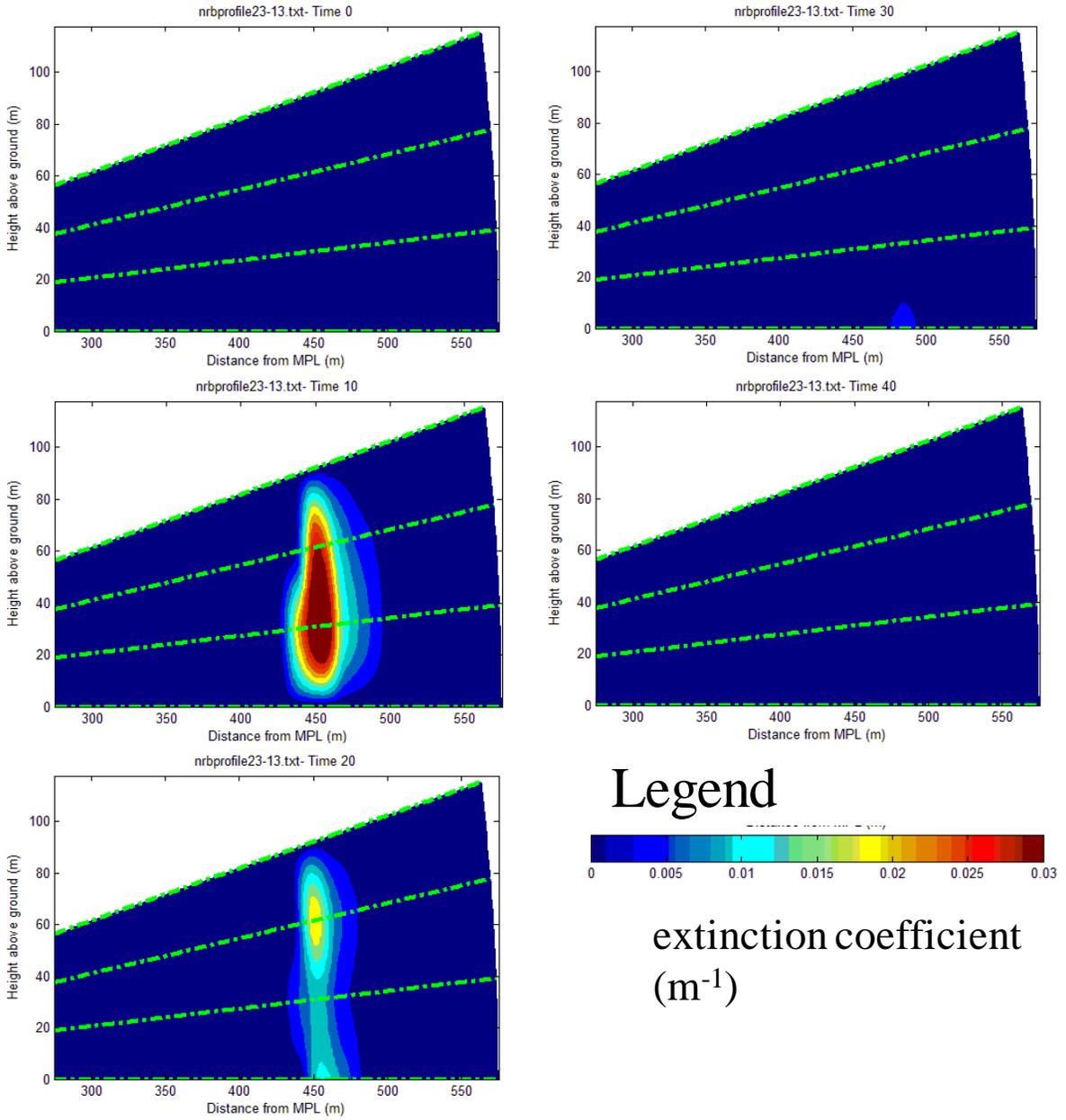


Figure 3-6. Time series of the 2-D light extinction profiles for an open detonation event.

Table 3-16 lists the individual and resulting MEE values and their standard deviations from simultaneous PM-10 mass concentration and total extinction values from the TEOMs and MPL, and the meteorological conditions when the tests occurred. MEE values were used to convert 1-D total extinction values to 1-D mass concentration values.

Table 3-16. Summary of mass extinction efficiency values for open burning and open detonation events

Open Burning (3/18/2010 data)			
Event	MEE (m²/g)	Wind Speed at 11.7m above Ground Level (m/s)	Wind Direction in cos(θ)^a at 11.7m above Ground Level
13	1.7	4.99	0.68
14	3.2	4.48	0.82
Average	2.5	4.73	0.75
Standard Deviation	1.1	0.37	0.10
Open Detonation (3/22/2010 data)			
Event	MEE (m²/g)	Wind Speed at 11.7m above Ground Level (m/s)	Wind Direction in cos(θ)^a at 11.7m above Ground Level
2	0.34	5.28	0.98
3	0.56	4.29	0.98
8	0.46	5.52	0.74
9	0.38	7.43	0.82
Average	0.44	5.63	0.88
Standard Deviation	0.10	1.31	0.12
^a =wind direction compared to measurement plane of the MPL			

Table 3-17 lists individual PM-10 emission factors for open burning events on 18 March 2010. The average and standard deviation for the PM-10 emission factors for open burning on 18 March 2010 are 0.0065 and 0.039 lb PM-10/lb NEW respectively. The relative standard deviation for those values is 60%.

Table 3-17. Individual PM-10 emission factors for open burning events (18 March 2010).

Open Burning Event Number	Individual Emission Factors (lb PM-10/lb NEW)
2	0.0072
3	0.0102
7	0.0028
8	0.0020
9	0.0019
10	0.0076
11	0.0082
12	0.0120
13	N/A

Open Burning Event Number	Individual Emission Factors (lb PM-10/lb NEW)
14	N/A
15	0.0104
16	0.0023
17	N/A
Average	0.0065
Standard Deviation	0.0039
Relative Standard Deviation (%)	60
N/A = not available due to MPL not scanning vertical for these tests	

Table 3-18 lists individual PM-10 mass emission factors for open detonation events on 23 March 2010. The average and standard deviation for the PM-10 emission factors for open detonation on 23 March 2010 are 0.20 and 0.11 lb PM-10/lb NEW respectively. The relative standard deviation for those values is 52%.

Table 3-18. Individual PM-10 emission factors for open detonation events (23 March 2010).

Open Detonation Event Number	Individual Emission Factors (lb PM-10/lb NEW)
1	0.26
3	0.11
4	0.08
5	0.38
7	0.24
8	N/A
9	N/A
10	0.13
11	0.25
12	0.08
13	0.31
Average	0.20
Standard Deviation	0.11
Relative Standard Deviation (%)	52
N/A = not available due to MPL not scanning vertical for these tests	

The open burning data on 18 March 2010 and the open detonation data on 23 March 2010 are presented separately because C/S values are only available during these two days. C/S cannot be determined during the other days because plumes were not detected on the ground level, where C/S values are calculated.

By assuming that C/S and MEE are constant in space and time, we can calculate emission factors measured for all days of the field campaign that C/S information is unavailable. This assumption can be made when we assume particle properties do not change significantly among OB/OD events, since both MEE and C/S relate to properties of dust, such as size, density, shape, and optical properties.

Table 3-19, Table 3-20, and Table 3-21 list individual PM-10 mass emission factors for open burning events on 16 March 2010, 17 March 2010, and 25 March 2010. There were no complete MPL scans of the plumes during March 15 due to the time needed to set up the equipment for complete measurements during the first day that UI was at the field site. These tables also report the average, standard deviation, and relative standard deviation values for each of these days.

Table 3-19. Individual PM-10 emission factors for open burning events (March 16, 2010)

Open Burning Event Number	Individual Emission Factors (lb PM-10/lb NEW)
6	0.0090
7	0.0144
8	0.0073
9	0.0121
10	0.0053
Average	0.0096
Standard Deviation	0.0036
Relative Standard Deviation (%)	38

Table 3-20 Individual PM-10 emission factors for open burning events (March 17, 2010)

Open Burning Event Number	Individual Emission Factors (lb PM-10/lb NEW)
1	0.0221
2	0.0074
3	0.0071
4	0.0053
5	0.0107
6	0.0065
7	0.0074

Open Burning Event Number	Individual Emission Factors (lb PM-10/lb NEW)
8	0.0030
9	0.0071
10	0.0122
11	0.0050
12	0.0080
13	0.0185
14	0.0079
15	0.0094
16	0.0066
17	0.0070
Average	0.0089
Standard Deviation	0.0048
Relative Standard Deviation (%)	54

Table 3-21. Individual PM-10 emission factors for open burning events (March 25, 2010)

Open Burning Event Number	Individual Emission Factors (lb PM-10/lb NEW)
2	0.0023
3	0.0012
4	0.0034
5	0.0112
6	0.0088
8	0.0091
Average	0.0060
Standard Deviation	0.0042
Relative Standard Deviation (%)	70

Table 3-22, Table 3-23, Table 3-24, and Table 3-25 list individual PM-10 mass emission factors for open detonation events on 19 March 2010, 20 March 2010, 22 March 2010, and 24 March 2010. These tables also report the average, standard deviation, and relative standard deviation for each of these days.

Table 3-22. Individual PM-10 emission factors for open detonation events (March 19, 2010)

Open Detonation Event Number	Individual Emission Factors (lb PM-10/lb NEW)
1	0.25
2	0.21
3	0.05
4	0.25
5	0.03
Average	0.16
Standard Deviation	0.11
Relative Standard Deviation (%)	67

Table 3-23. Individual PM-10 emission factors for open detonation events (March 20, 2010)

Open Detonation Event Number	Individual Emission Factors (lb PM-10/lb NEW)
7	0.23
8	0.25
9	0.43
10	0.91
Average	0.45
Standard Deviation	0.32
Relative Standard Deviation (%)	70

Table 3-24. Individual PM-10 emission factors for open detonation events (March 22, 2010)

Open Detonation Event Number	Individual Emission Factors (lb PM-10/lb NEW)
1	0.16
10	0.04
Average	0.10
Standard Deviation	0.08
Relative Standard Deviation (%)	89

Table 3-25. Individual PM-10 emission factors for open detonation events (March 24, 2010)

Open Detonation Event Number	Individual Emission Factors (lb PM-10/lb NEW)
1	0.33
2	0.09
3	0.20

Open Detonation Event Number	Individual Emission Factors (lb PM-10/lb NEW)
4	0.23
5	0.18
Average	0.21
Standard Deviation	0.09
Relative Standard Deviation (%)	43

A summary of PM-10 mass emission factors with their relative standard deviations, when available for OB and OD events measured by ORS on March 18 and 23, 2010, respectively, are described in Table 3-26. Results from these two days are shown because C/S values were calculated on these days at the ground level. The table also shows the summary of PM-10 mass emission factors measured by ORS for all successful events with the constant C/S and MEE assumptions. Results are also provided based on draft AP-42 emission factors and USEPA's measurements with the Flyer and when their instruments were co-located with the TEOMs.

Table 3-26. Summary of PM-10 emission factors for open burning and open detonation events

Test Type and Emission Factors		Open Burning of M1		Open Detonation of TNT	
		Emission Factor	Relative Standard Deviation	Emission Factor	Relative Standard Deviation
PM-10 (lb/lb NEW)	Existing	6.9E-03	41%	7.2	47%
	Flyer	5.7E-03	DNA	0.13	54%
	Scissors Lift	7.7E-03	DNA	0.97	DNA
	MPL (Mar 18 and 23 only)	6.5E-03	60%	0.20	52%
	MPL (all days)	7.9E-03	56%	0.23	78%

DNA = does not apply

The effect of scaling in determination of PM-10 emission factors was also investigated for MPL measurements of OD events. OB events were not studied because all OB events used 100 lb of M1 propellant. For OD tests, explosives were detonated using 50 lb and 100 lb quantities. A t-test was performed between the average emission factors, measured by the MPL method, for events using 50 lb of TNT and 100 lb of TNT. Results are shown in Table 3-27. The two-tailed p-value is 0.30, meaning that at a 95% confidence level, the two average emission factors are not significantly different. It is therefore encouraging to observe that scaling up the OD events between 50 lb and 100 lb does not affect the PM-10 emission factors.

Table 3-27. Statistical tests of PM-10 emission factors of 50 lb and 100 lb OD events measured by the MPL method

NEW (lb)	50	100
# of Events	11	14
Mean (lb PM/lb NEW)	0.27	0.19
Standard Deviation (lb PM/lb NEW)	0.24	0.10
p-value of Two-tailed t-test	0.303	

In summary, the PM-10 measurement results obtained by the ORS method are encouraging in that these measurements are in general agreement with independent measurements completed by the EPA’s Flyer measurement system. The assumption of constant C/S and MEE does not significantly affect the resulting averaged PM-10 mass emission factors. Also, the difference in emission factors between the 50 lb and 100 lb detonations is insignificant, suggesting that scaling up the amount of explosives does not affect the PM-10 emission factor in the 50 lb to 100 lb detonation range.

3.3 ORS for Gases

The dates of the OB and OD tests, the number of tests during each day, and the successful measurements for the OP-FTIR, UV-DOAS, and solar occultation FTIR are presented in Table 3-28.

Table 3-28. Description of test dates for open burning and open detonation tests and percentage of successful tests

Date	Day	Type of Test	Total Number of OB or OD Tests	Successful Tests		
				OP-FTIR	UV-DOAS	Solar Occultation
15-Mar	M	OB	5	0	0	NA
16-Mar	T	OB	10	0	1	NA
17-Mar	W	OB	17	10	15	4
18-Mar	R	OB	17	7	7	7
19-Mar	F	OD	5	4	0	0
20-Mar	SA	OD	10	0	0	3
22-Mar	M	OD	10	10	0	4
23-Mar	T	OD	13	10	0	8
24-Mar	W	OD	7	2	0	5
25-Mar	R	OB	8	0	7	2
OB Tests, Sum			57	17	30	13
Successful OB Tests (%)				30	53	23
OD Tests, Sum			45	26	0	20
Successful OD Tests (%)				58	0	44

OB tests were conducted on March 15th through March 18th and March 25th. OD tests were conducted on March 19th through March 24th. As shown in Table 3-28, the days with the highest rate of successful OB tests are March 17th and March 18th. The day with the highest rate of successful OD tests is March 23rd. For this initial evaluation, March 18 and March 23 data are analyzed and presented herein.

3.3.1 Open Burning Results

Table 3-29 summarizes all the average concentrations (per event) of gases detected during the open burning events on March 18. The reported CO₂ concentrations are levels above the measured background concentration. As test method TO-16 requires, data quality indicators are evaluated and reported for each spectrum analyzed. Particle load is the main reason for changes in MDL as the signal decays and MDLs increase with larger loads.

Table 3-29. OB gas average concentrations as measured by the OP-FTIR (March 18, 2010)

event	CO ₂	MDL	CO	MDL	NO	MDL	NO ₂	MDL	NH ₃	MDL	Ethylene	MDL
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
1	110	23	0.39	0.04	1.77	0.21	ND	0.05	ND	0.017	ND	0.034
6	12	4	0.32	0.02	0.38	0.07	ND	0.03	ND	0.002	0.014	0.0032
8	13	3	0.16	0.01	0.17	0.05	ND	0.03	ND	0.002	ND	0.0039
9	101	11	0.64	0.064	1.3	0.31	ND	0.047	0.0057	0.003	ND	0.0064
10	ND	12	0.18	0.025	ND	0.13	ND	0.044	ND	0.007	ND	0.0050
13	15	3.7	0.35	0.033	0.92	0.18	ND	0.050	ND	0.003	ND	0.0051
14	50	7.4	0.10	0.027	ND	0.21	ND	0.055	ND	0.0033	ND	0.013

In all March 18 events, CO was detected and CO₂ was detected during six of the events. The event during which CO₂ was not detected (Event 10) was not the event with the lowest CO concentration, indicating a poor correlation between CO and CO₂ across the OB events. The poor correlation is a strong indicator of problems with the measurements since CO and CO₂ are normally strongly correlated in emissions from combustion events. NO was not detected during Event 10 and also not detected during the event with lowest CO concentration (Event 14). Ammonia was detected during Event 9 and ethylene was detected during Event 6. Both ammonia and ethylene were also detected during open burning events on March 17.

NO was also detected by the UV-DOAS at slightly lower levels on average. This negative bias could be a result of the slightly different location of the sampled path and a different time intervals between the two instruments. This also can be a result of large particle extinction at the NO UV spectral region as is shown in Figure 3-7 below. Due to these issues, this data set was not used for EF calculations. The OP-FTIR provided reliable simultaneous measurement of NO and the other detected gases, and therefore provided along with the MPL plume dimension data the required information for EF calculations. Figure 3-7 shows the averaged UV spectra for all OB events measured (time averaging method). The elevated and sloped baseline is a result of strong particle extinction in this spectral region and also a result of the cut off region of the spectrom-

ter sensitivity towards 200 nm. The three sharp absorption lines are due to detected NO as demonstrated in Figure 3-8 that shows the UV reference spectra of NO at several levels. The evidence of three NO lines in the measured spectrum is obvious at 204 nm, 214 nm, and 226 nm. However, the relative strength of these lines is not accurate when compared to the reference spectra in Figure 3-8. The measured NO line is getting non-proportionally weaker towards the detector cut off. Therefore, detection is confirmed but quantification of NO may be erroneous due to these issues mentioned above.

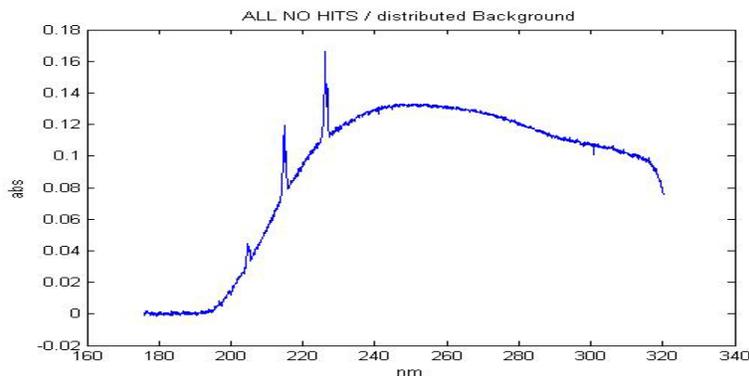


Figure 3-7. Averaged UV spectra for all OB events measured

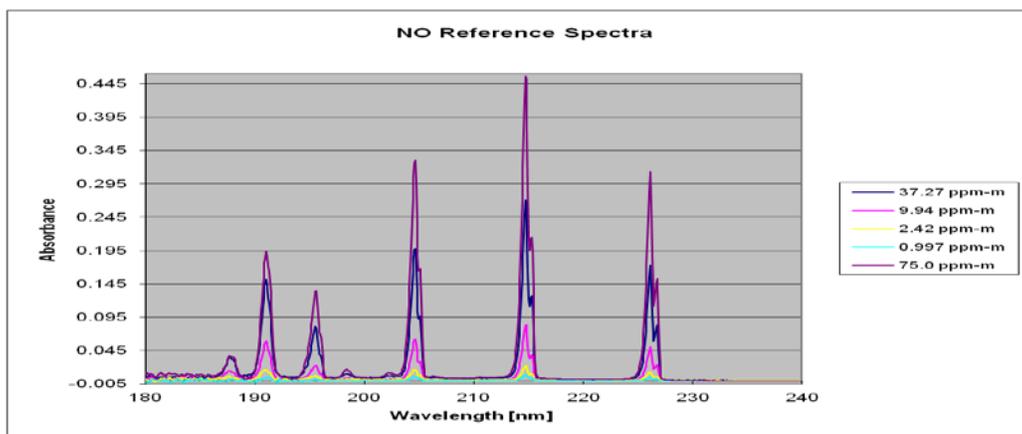


Figure 3-8. NO reference spectra at five concentration levels

It is apparent from Figure 3-7 that no other gases were detected during the OB events. Figure 3-9 provides the reference spectra for benzene at three concentration levels. Benzene has two absorption lines at 253 nm and 259 nm and no benzene lines are present in the averaged measured spectra as shown in Figure 3-10.

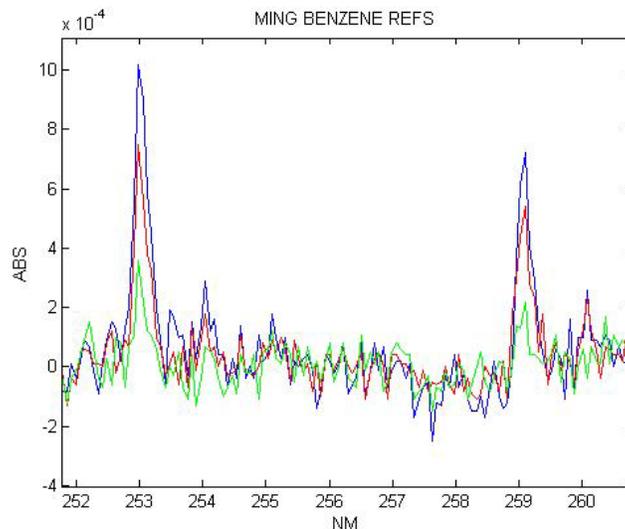


Figure 3-9. Benzene reference spectra at three concentration levels

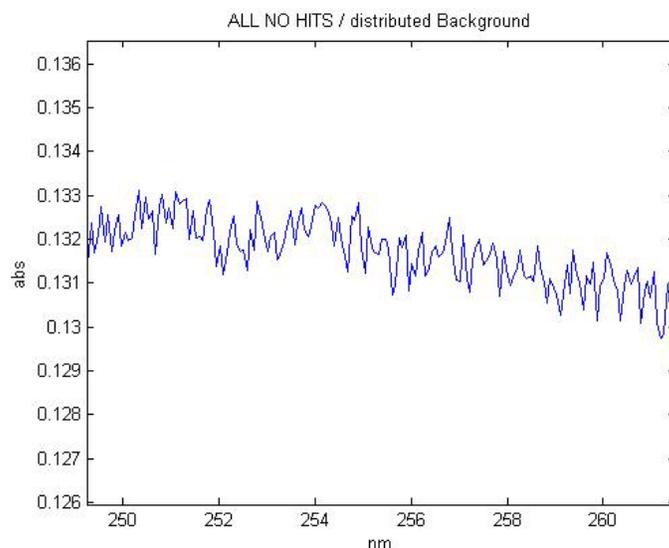


Figure 3-10. Averaged UV spectra for all OB events measured in the benzene absorption spectral region

A summary of MDLs for the compounds not detected by the OP-FTIR instrument (e.g. benzene, and naphthalene) for both OB and OD events are provided below at the end of this section (Table 3-32).

Figure 3-11 and Figure 3-12 provide OP-FTIR visual spectral validation for the detection of CO, CO₂, and NO during OB events.

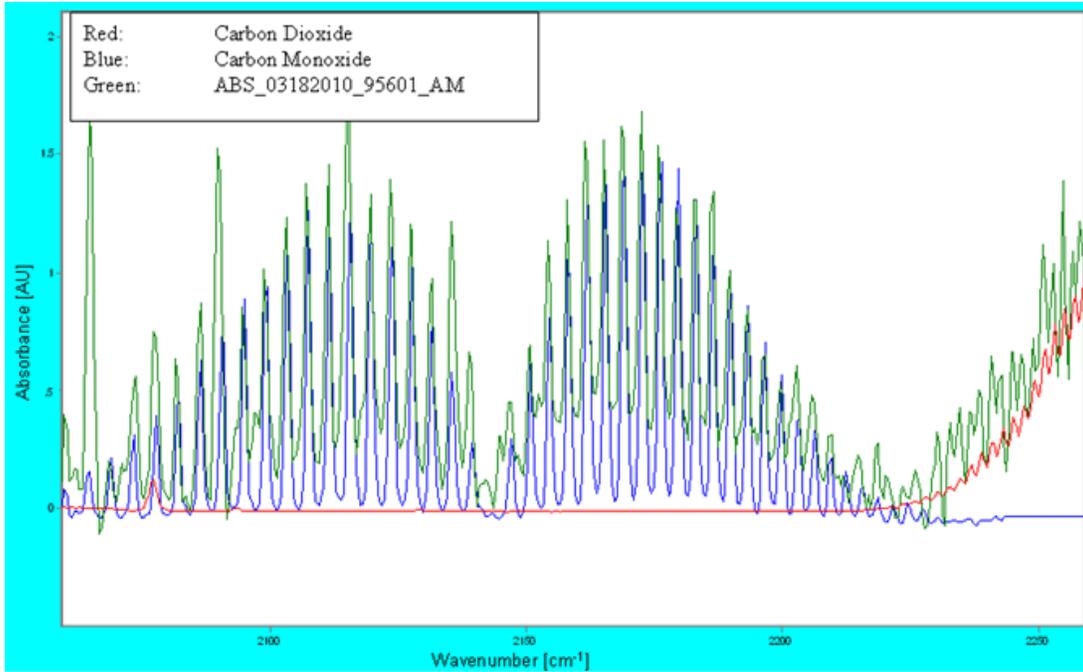


Figure 3-11. Spectral validation for CO and CO₂ detection for OB on March 18

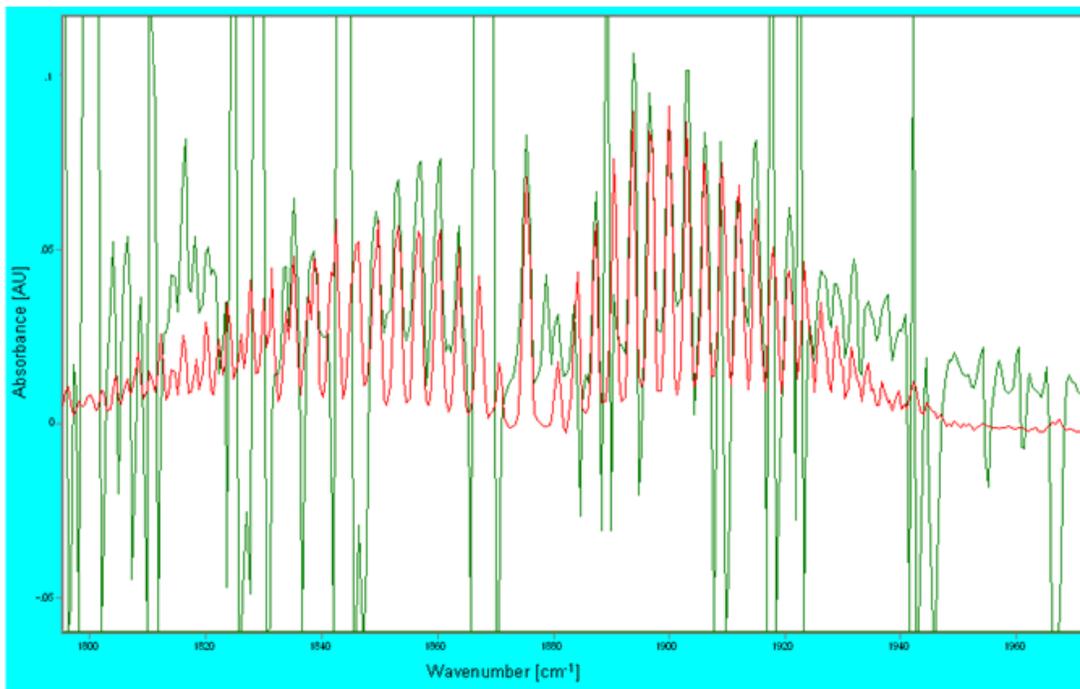


Figure 3-12. Spectral validation for NO detection for OB on March 18

Figure 3-13 and Figure 3-14 indicate different particle content in two OB events. Figure 3-13 shows a very high concentration of CO and CO₂ in event 1 without any PM extinction baseline

shift (actually the data shows a slightly negative shift) indicating that this part of the detected plume had no PM load. In contrast, Event 6 shown in Figure 3-14 has a large baseline shift, indicating a negative correlation between PM and gases in the plume. This is confirmed by the MPL extinction data for a path that includes the location of the OP-FTIR, in which extinction values were much higher at event 6 than in event 1 data as shown in Table 3-30.

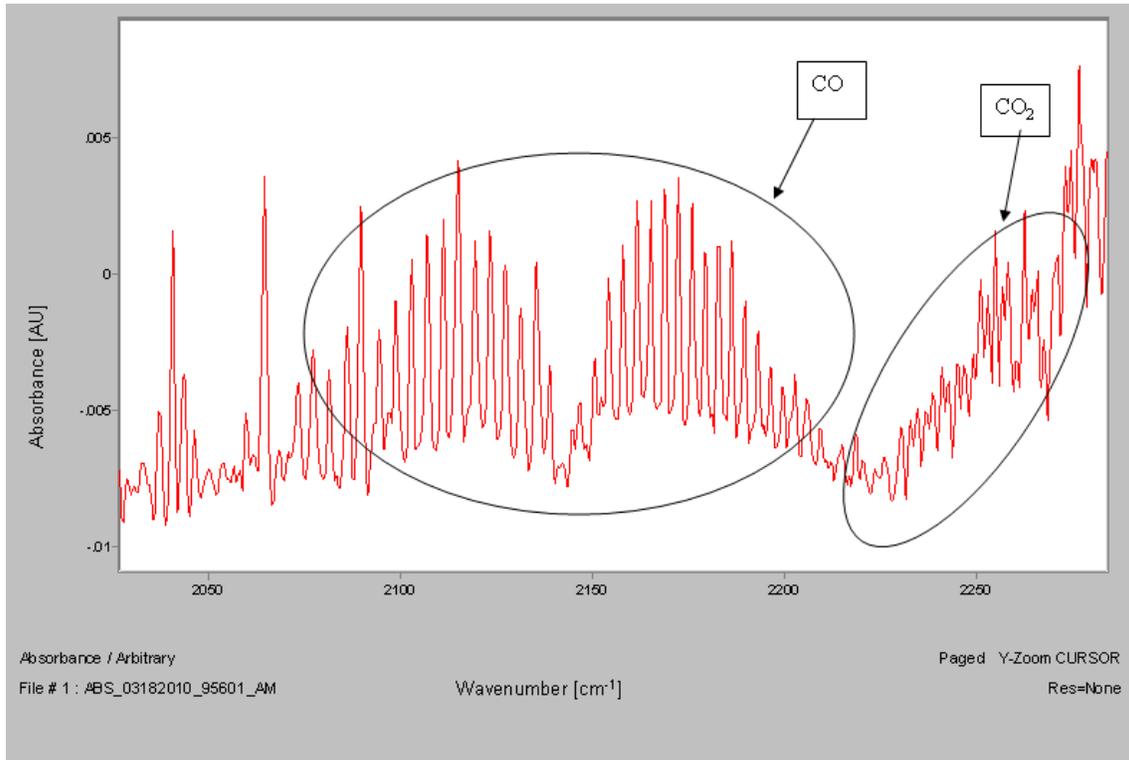


Figure 3-13. Average spectrum for OB event 1 on March 18 showing the detected CO and CO₂ absorption features and no baseline shift

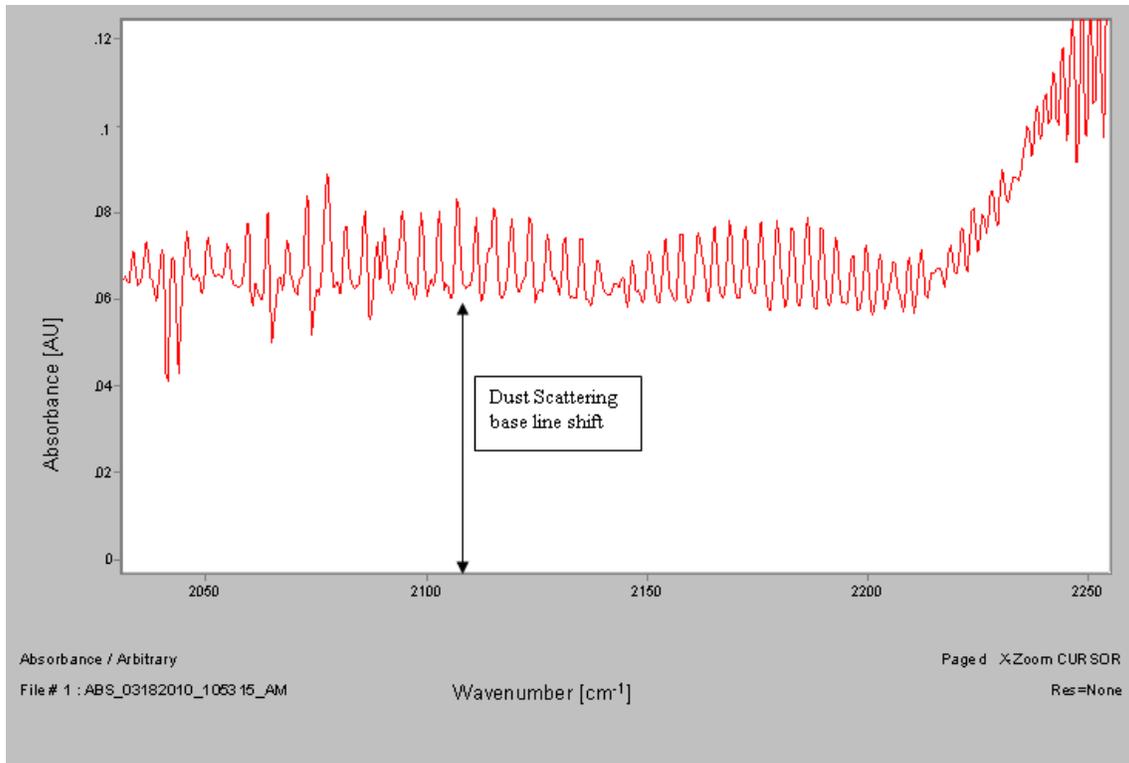


Figure 3-14. Average spectrum for OB event 6 on March 18 showing the detected CO and CO₂ absorption features and large baseline shift

Table 3-30. MPL extinction data at OP instrumentation location for 3 OB events

Event	Average Extinction (m ⁻¹)	Bin range Averaged	MPL scan angle (deg)
1	5.8E-05	21-24	1.212
6	2.3E-03	21-24	1.212
8	1.0E-05	21-24	1.212

3.3.2 Open Detonation Results

Table 3-31 summarizes average concentrations per event detected in the OD events on March 23. Again, CO was detected during all events as shown in Figure 3-15 and with the familiar dust extinction feature (Varma et al., 2007) as shown in Figure 3-16. Since measurements during OD events occur further downwind than during OB events, CO₂ and NO are only sporadically detected and the measured concentrations are very close to detection limit. However, the lack of CO₂ detection during events with the largest CO concentrations is a strong indicator of problems with the measurements since CO and CO₂ are normally strongly correlated in emissions from combustion events. In addition, NO₂ was detected at or very close to the detection limit. Acetylene was detected in several events and spectral validation is provided in Figure 3-17. The slope

in the spectrum is associated with PM extinction. These compounds are detected in similar patterns on other days of open detonation.

Table 3-31. OD gas average concentrations as measure by the OP-FTIR

	CO ₂	MDL	CO	MDL	NO	MDL	NO ₂	MDL	Acetylene	MDL
event	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
1	ND	1.6	0.28	0.02	ND	0.01	ND	0.03	0.0034	0.0010
2	4.1	1.4	0.20	0.01	ND	0.02	ND	0.02	ND	0.0017
4	ND	2.0	0.35	0.02	ND	0.02	ND	0.02	0.0051	0.0013
6	ND	4.2	0.43	0.03	ND	0.04	ND	0.03	ND	0.0028
8	6.6	2.8	0.25	0.02	ND	0.07	ND	0.03	ND	0.0028
9	ND	8.0	1.4	0.10	0.30	0.12	ND	0.09	0.037	0.0067
10	ND	4.5	0.37	0.03	ND	0.11	ND	0.05	ND	0.0044
11	ND	6.2	0.43	0.04	ND	0.09	0.16	0.06	ND	0.0042
12	ND	8.6	0.71	0.06	ND	0.15	0.20	0.09	0.017	0.0078
13	ND	2.8	0.16	0.01	ND	0.05	ND	0.02	ND	0.0034

The UV-DOAS did not detect any compounds during any of the OD events. The time averaged method was applied in an effort to detect benzene and NO₂ across all OD or OB events with the UV-DOAS. None of these compounds was detected above 1 ppb for benzene and above 10 ppb for NO₂.

Figure 3-15 and Figure 3-16 indicate different particle content in two OD events (both 100 lb TNT). Event 11 (Figure 3-15) has little dust PM (horizontal ellipse in Figure 3-15) however it does show very large unknown derivative-shaped features (vertical ellipse in Figure 3-15) that may be associated with non-dust PM absorption (Varma et al., 2007). These could be transitional aerosol compounds and should be investigated further. In contrast, Figure 3-16 shows event 9 with a large amount of dust and much smaller amounts of non-dust PM. Also, the baseline shift in this event is much larger and, unlike the OB events, this event shows much higher CO concentrations than with Event 11. This could be very valuable data for calculating mass extinction efficiency for the MPL/TEOM PM-10 flux calculations. This is an opportunity to develop two different extinction efficiencies for the two primary types of PM regimes.

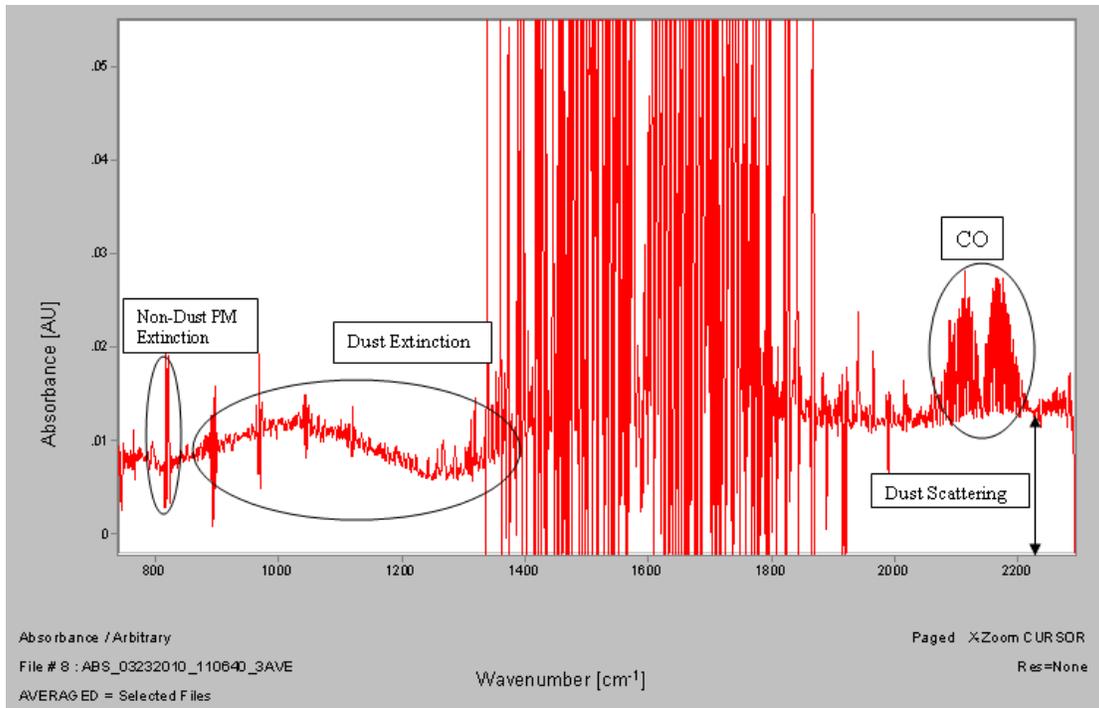


Figure 3-15. Average spectrum for OD event 11 on March 23 showing the detected CO, dust, and large non-dust PM absorption features.

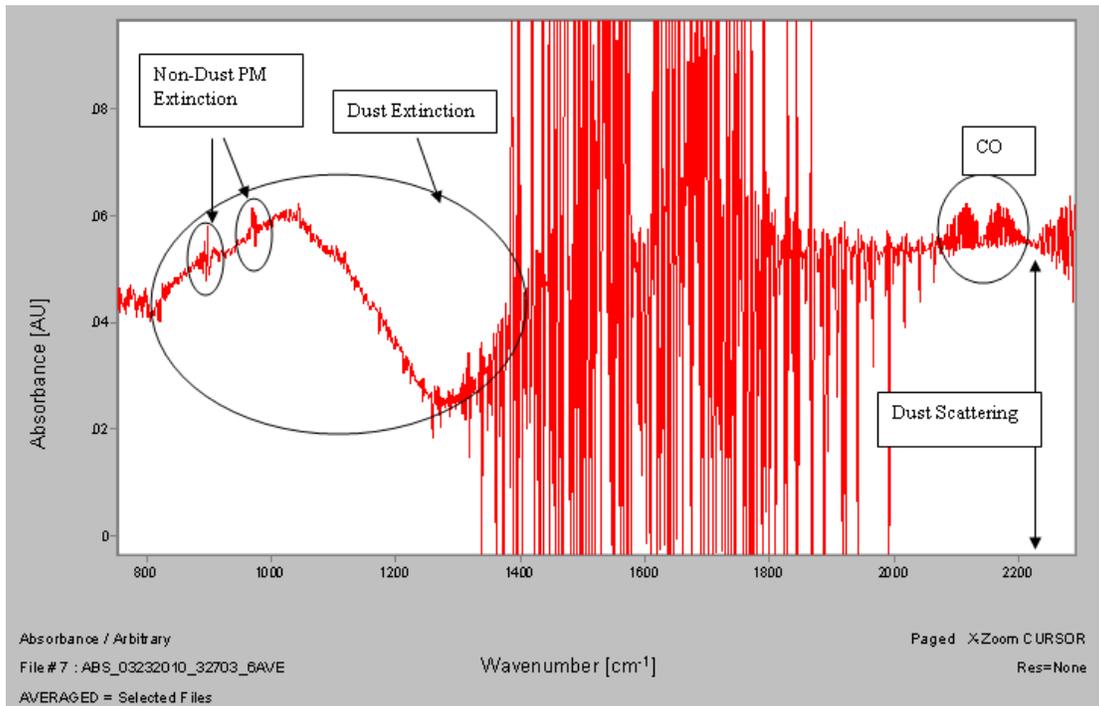


Figure 3-16. Average spectrum for OD event 9 on March 23 showing the detected CO, dust, and small non-dust PM absorption features.

Figure 3-17 provides an OP-FTIR spectral validation for the acetylene detection during the OD events.

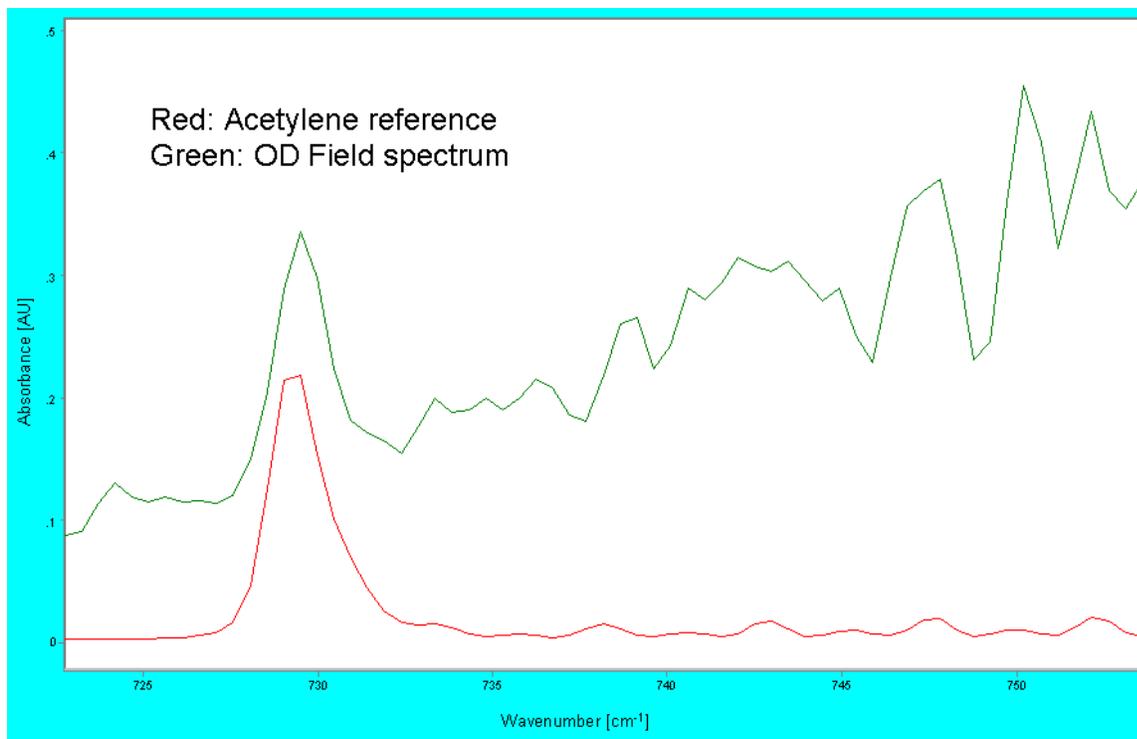


Figure 3-17. Spectral validation for the acetylene detection on March 23

Table 3-32 summarizes the MDL for several compounds that were not detected using the ORS Time-Averaging Method. All the absorption spectra for each day were averaged and then the classical least squares analysis performed. It is worth noting the high sensitivity of the CH stretch region of the spectrum as n-octane. Despite the low detection limit, no evidence of hydrocarbons was detected in both OB and OD.

Table 3-32. Minimum detection limit of gases not detected by the OP-FTIR

	Benzene [ppb]	Napthalene [ppb]	CH Stretch as n-Octane [ppb]
OB	82	20	2
OD	66	9	1

The two solar occultation instruments were located very far downwind (safety considerations) but nevertheless many OD PM plumes were captured by both passive FTIR instruments. This can be observed by the baseline shift in Figure 3-18. Evidence of CO₂ and CO can be observed in some spectra but the concentrations are very close to the system MDLs which in the case of

CO₂ is estimated at about 500 ppm above background. At this remote location downwind it is not a surprise that CO₂ and CO were not often detected as the OP-FTIR had difficulties monitoring CO₂ much closer to the source.

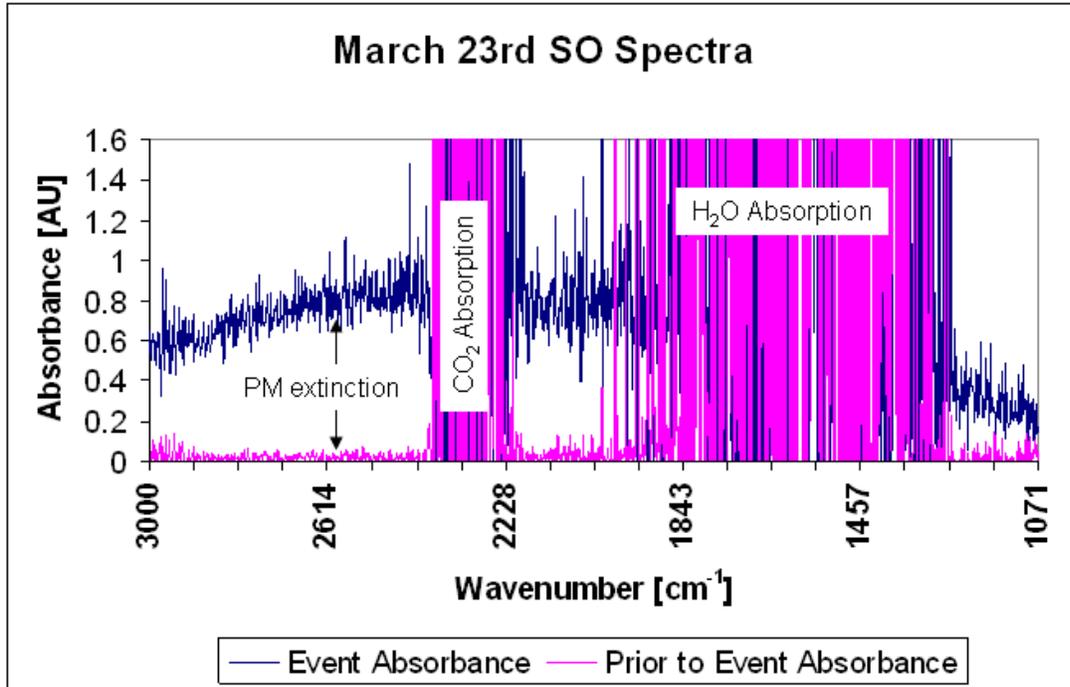


Figure 3-18. Spectral evidence of PM and CO₂ detection from OD on March 23 by the IMACC solar occultation system

3.3.3 Emission Factor Calculation Results

The EFs were calculated using Equations 2-15 through 2-18 for all gases detected by the OP-FTIR during events that the MPL data was sufficient. The results are presented in Table 3-33 for the OB applicable events on March 18th and in Table 3-34 for the OD applicable events.

Table 3-33. Results of EF calculations for all OB successful events on March 18th

	CO	NO	Ethylene	Ammonia
Event	lb/lb NEW	lb/lb NEW	lb/lb NEW	lb/lb NEW
1	2.3E-03	1.1E-02	ND	ND
6	1.7E-02	2.2E-02	7.4E-04	ND
8	7.8E-03	8.9E-03	ND	ND
9	4.0E-03	8.8E-03	ND	2.2E-05
10	9.5E-03	ND	ND	ND
Average	8.1E-03	1.3E-02	NA	NA
Std	5.7E-03	6.1E-03	NA	NA

Table 3-34. Results of EF calculations for all OD successful events on March 23rd

	CO	NO	NO₂	Acetylene
Event	lb/lb NEW	lb/lb NEW	lb/lb NEW	lb/lb NEW
4	1.1E-01	ND	ND	1.5E-03
6	6.5E-02	ND	ND	ND
10	5.2E-02	1.7E-02	ND	ND
11	4.4E-02	ND	2.7E-02	ND
12	5.3E-02	ND	2.4E-02	1.2E-03
13	3.6E-02	ND	ND	ND
Average	6.0E-02	NA	2.6E-02	1.3E-03
Std	2.7E-02	NA	1.9E-03	2.4E-04

One can observe that EFs for CO are almost an order of magnitude larger for OD than OB. Emission factor variability for OB is larger than OD. This could be due to the proximity of the OP-FTIR to the OB source and the short duration of the detected events. Furthermore, the orientation of the OP-FTIR line-of-sight relative to the MPL line-of-sight is significantly off by about 60° for the OB source. These mismatches in time and space for OB introduced error to the EF calculations. This can potentially be avoided by measuring further downwind where the plumes are larger and the events are longer, and also by making sure that the OP-FTIR is co-aligned with the MPL. Poor correlation between CO and CO₂ for both OB and OD measurements is another indicator of problems with ORS gas measurements and the potential for error when calculating EFs. Since NO₂ was not detected for OB and NO was almost not detected for OD (probably due to location of measurements) it is difficult to compare nitrogen oxides EFs between the OB and OD. The EF for the ammonia illustrates the lower limit of EF measurements by this system (OP-FTIR/MPL hybrid) of about 10⁻⁵ lb/lb NEW.

3.3.4 QA/QC

Beyond the visual spectral validation provided herein, the N₂O calibration procedure detailed within TO-16 was performed and passed. Randomly 60 spectra files were selected for the N₂O QC check. As stated in the Test Plan, the N₂O concentration determined from OP-FTIR measurements should be within ± 25% of the global atmospheric background concentration of 315 ppb (or 0.315 ppm). Table 3-35 provides information on the test result. Both accuracy and precision are well within the allowed boundaries as stated in the Test Plan. Figure 3-19 demonstrates the detection of N₂O with the OP-FTIR system.

Table 3-35. Results of N₂O OP-FTIR QC check

	N ₂ O Concentration (ppm)
Average	0.329
Standard Deviation	0.015
Accuracy	5%
Precision	5%

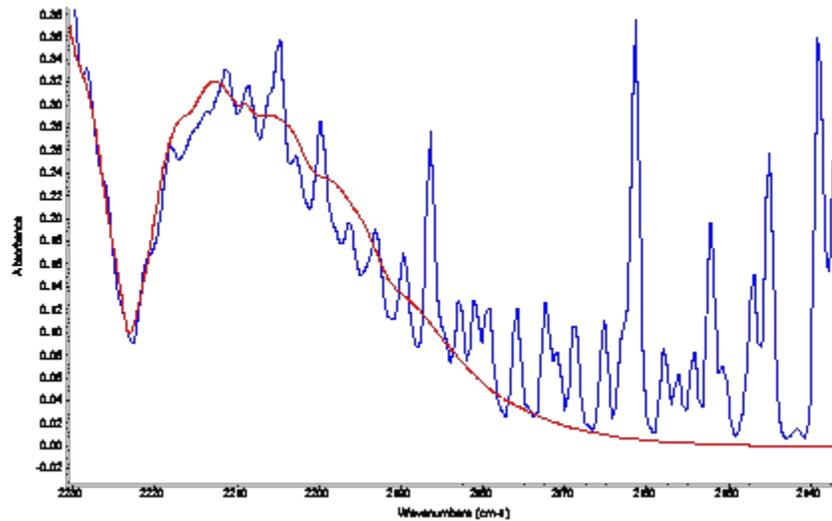


Figure 3-19. Spectral validation for the N₂O QC test (blue line is the measured spectrum and the red line is the reference spectrum of N₂O)

3.4 Plume Detection and Sampling Capabilities of Individual Methods

Both in-situ and ORS measurements have strengths and weaknesses in terms of their abilities to effectively sample or detect emissions in OB/OD plumes. The methods evaluated in this project's field campaign were designed to complement each other. During the 2-week field campaign, we experienced all types of weather conditions typical of Tooele Army Depot in March including rapid and drastic changes in wind direction and speed. The changing and unpredictable wind conditions were challenging and each measurement system was most effective under different conditions:

1. Aerial sampling by the tethered balloon was very effective in both low and high wind speeds. The mobility provided by the ATV arrangement and the use of highly trained aviation experts enhanced the sampling effectiveness.
2. The MPL was effective under most conditions due to its ability to scan through complete vertical slices of the passing OB and OD plumes. Higher wind speeds limited the number of complete scans the MPL could make through the plume.

3. Ground-based ORS and TEOM plume detection and sampling effectiveness was enhanced at high wind speeds which held the plume close to the surface and greatly reduced at low wind speeds where thermal diffusion resulted in rapidly rising plumes.

The vertical movement of the plume was generated from the detonation energy and large vertical temperature gradients. Horizontal movement was mainly due to advection from the wind. At high wind speeds, ground measurements taken with the scissor lift captured more plumes than originally expected. Since the passive FTIR needed a line of sight through the plume to the sun, there were concerns about plume capture. However, the data showed that the passive FTIR was at times successful in detecting the plumes. Since all the measurement technologies were at least partially successful in detecting or sampling plumes, it is difficult to eliminate any of the technologies based entirely on sampling or plume detection capability. Some of the limitations can be overcome by improving measurement system designs based on the lessons learned during this field campaign.

3.5 Method Improvements/Lessons Learned

3.5.1 Flyer Sampler

The Flyer achieved a high plume sampling success of 76 to 85%, as indicated by the frequency with which the CEMs recorded elevated CO₂ levels from both OB and OD plumes. The Flyer achieved a high success rate in both low and high winds. Wind shifts, rather than higher speeds, were more problematic for positioning the Flyer in the plume. Remote control of the ATV mounted tethers was not successful at Tooele Army Depot due to limitations of the receivers, which failed to meet their manufacturer's claims. This is a current topic for improvement and remote control of the tethers will allow repositioning of the Flyer after detonation event initiation, further improving plume capture percentage.

The CEM system, VOC sampler, and semi-volatile sorbent all proved to be successful systems for sampling. The VOC sampler, however, needs the selection of a different electronic valve to prevent leaks. A revised quality control methodology is also being developed.

The balloon flight operations and the performance of the Flyer instrumentation made it possible to successfully determine emission factors, meeting the objectives of the first year's work. Further, these emission factors agree with the few published data available using comparable ordnance and sampling methods. These emission factors were also derived quickly, some while in the field and the last within 4 weeks of field sampling.

Improvements in instrumentation, sampling, and quality control procedures, and in balloon flight operations are under consideration or in-process. These include in-flight transmission of CO₂ and video data, remote control of Flyer position via radio-controlled tether spools, balloon release mechanisms and shelters for fragmenting detonations, powered tethers, and use of lighter Li-ion batteries.

Improvements in the operating methods and instrumentation of the Flyer, and in the tether deployment system, are expected to significantly improve the data quality. The apparent success of at least the first Summa canister suggests that the method works well, but requires different valves and pre-sampling quality assurance procedures. The high frequency of successful balloon samples (Table 3-1) can be expected to increase with modifications to the ATV/tether system. The addition of radio-controlled and turntable-mounted winches will allow rapid changes to be made even when operators must maintain a lengthy safety distance (> 1500 ft). This will allow for an even higher frequency of plume “catches” than by pre-location alone. These hardware and procedural modifications are underway.

3.5.2 LIDAR and TEOM

The limitations of the aerosol sampling instrumentation can be reduced by the following improvements:

- 1) Increase the resolution of the distances where the backscatter signals are measured by the MPL to increase the number of data points measured across the plume,
- 2) Increase the rate of vertical scanning of the MPL that is located on the positioner to increase the number of vertical sampling points within the plume,
- 3) Provide more flexibility when locating the TEOMs in the plume to increase the probability that TEOMs measure the plume concentration,
- 4) Verify the mass concentration measurement of the TEOMs with an independent mass concentration measurement such as an aerodynamic particle sizer (APS), and
- 5) Deploy 3-D wind sensors instead of the using 2-D wind sensors to more accurately measure wind speed and direction along the measurement cross-sections of the plumes.

The current length resolution to measure backscatter signals from the MPL is 15 m. Sigma Space Inc. has indicated that the MPL used at Tooele Army Depot can be modified with software and firmware to improve the resolution of its backscatter measurement to 1.14 m with a maximum range of 9.3 km.⁴

The University of Illinois is working to modify the scanning software of the positioner to allow for more rapid scans by providing feedback between the MPL and the positioner so that maximum scanning angles can be determined during the detection of each plume instead of defining the scanning angles before each event.

Greater flexibility of locating the TEOMs in the plume can occur with the use of hydraulic truck cranes. These cranes can rotate the TEOMs about the vertical centerline of the crane and provide

⁴ Personal communication with Ed Leventhal of Sigma Space Inc.

maximum weight and height lifting capacity ranging from 18 to 550 tons and maximum vertical lifting capacity ranging from 5.5 to 133 m.⁵ Such flexibility allows the TEOMs to be located in a wide range of locations within the plume, including the centerline of the plumes, due to the lifting and rotational capacity of these cranes.

Verification of the PM mass concentration measurement by the TEOMs could occur in the field by co-locating an APS with the TEOMs to compare the measurements by both devices. The APS provides PM size distributions that can be converted to mass concentration and then compared to results measured by the TEOMs.

Wind speed is determined with two 2-D anemometers located at two elevations. The results from these measurements are then used to develop a power law relationship to describe wind speed dependence on height. Another approach to measure wind speed and direction is to replace the 2-D anemometers with 3-D anemometers. The 2-D anemometers take into consideration changes in speed and direction in the horizontal plane. The 3-D anemometers allow characterization of wind speed and wind direction in 3-D.

3.6 Measurement of PM Emissions from OB/OD

For the OD of TNT, the PM-10 emission factor derived from Flyer measurements was 0.13 lb/lb NEW, the emission factor derived from the ORS-based PM measurement method was 0.20 lb/lb NEW, and the existing emission factor data was 7.2 lb/lb NEW. Although the ORS-based PM measurement method emission factor was twice that of the Flyer derived value, the two values were still remarkably close considering the fundamental difference in the two measurement systems. The published value is much higher indicating the potential importance of local conditions on the amount of soil PM that can be entrained in an OD plume. The published PM-10 value has an AP-42 Quality Rating of D, which indicates the potential for large variability in the reported value. For the OB of M1 propellant, the PM-10 emission factor derived from Flyer measurements was 5.7E-03 lb/lb NEW, the emission factor derived from the ORS-based PM measurement method was 6.5E-03 lb/lb NEW, and the existing emission factor was 6.9E-03 lb/lb NEW. This remarkable consistency among the three values may be a function of the appropriateness of both PM measurement methods used in the field campaign for determining OB emission factors. This close agreement is also strong evidence that both PM measurement systems used in the field campaign worked well for OB PM-10 emissions. Future work to determine OB/OD emission factors should consider the continued use of both PM measurement systems as a way to help validate the results from both systems.

3.7 Measurement of Gas Emissions from OB/OD

The emission factors for the two target gases benzene and naphthalene derived from Flyer measurements were quite close to existing published values (AP-42 2009) (Table 3-8). The Flyer was

⁵ <http://www.cranerental.com/>

also able to measure other PAHs and emission factors were again comparable to published values when they were available (AP-42 2009) (Table 3-9). These results and the proven capability of using the balloon to place the Flyer in the plume are a strong indicators of the Flyer measurement system's capability to accurately assess both volatile and semi-volatile organic gas emissions.

In contrast, the ORS measurement systems were not able to detect the target gases and therefore no comparison could be made between the two types of gas measurement systems. The OP-FTIR was able to consistently detect CO and sporadically detect NO, NO₂ ethylene, ammonia, and acetylene (Table 3-29 and Table 3-31). The OP-FTIR was able to measure CO₂ for most OB events but the correlation between CO and CO₂ was very poor. The poor correlation is a strong indicator of problems with the measurements since CO and CO₂ would normally be strongly correlated in emissions from combustion events. For OD, very few of the plumes where CO was detected also had a corresponding CO₂ detection. The emission factors derived from OP-FTIR measurements for CO were 8.1E-03 lb CO/lb NEW for OB and 6.0E-02 lb CO/lb NEW for OD (Table 3-33 and Table 3-34). This corresponds to 2.2 E-02 lb CO/lb C for OB and 1.6E-01 lb CO/lb C for OD and the published values for CO emission factors are 8.2E-04 lb CO/lb C for OB and 1.5E-01 lb CO/lb C for OD (AP-42 2009). The OD CO emission factor derived from the OP-FTIR measurements is very close to the published value while the OB CO emission factor is not close. The OB CO emission factor may suffer from the problem of not having the OP-FTIR and MPL lines-of-sight aligned with each other as discussed in Section 3.3.3. Alternatively, it may represent inefficient combustion for OB during the field test.

The UV DOAS detected NO in OB and OD plumes but provided no additional information compared to the OP-FTIR data. The time averaged method was applied in an effort to detect benzene and NO₂ across all OD or OB events. None of these compounds were detected above 1 ppb for benzene and above 10 ppb for NO₂. These results are consistent with the OP-FTIR results. If benzene was detected at this level, it would result in an EF on the order of 10⁻⁵ lb/lb NEW which is very high for benzene. Therefore, it makes sense that benzene was not detected. It is recommended not to use a UV DOAS system in future OB/OD studies.

The passive FTIR should be used only if it can be located in proximity to the MPL plane. Data collected in a far away plane have no benefit for the overall ORS monitoring system. These systems can be very useful if located at the same location as the MPL plane and closer to the source. They are capable of detecting gases in a path between the instrument and the sun and may provide sensitive CO and CO₂ detection through lofted plumes. In order to be applied in future studies, these systems must be unmanned during the OD events. This can be achieved by a heliostat (computerized sun tracker) mounted on a static passive FTIR. For the several OB events where it detected the plume, there were no additional benefits beyond what we achieved with OP-FTIR and the potential usefulness of the passive FTIR system was not demonstrated. Therefore, it is also recommended not to use this system in future studies.

4. Conclusions and Implications for Future Research

4.1 Conclusions

Overall, the study was successful in determining the feasibility of the deployed measurement systems. The field campaign and its data analysis results clearly indicated that many of the deployed systems can become powerful tools to characterize air emissions from field OB/OD operations.

As discussed above, all of the measurement systems were at least partially successful in plume sampling and plume detection. Three distinct instrumentation set-ups each have their own niche, strength and weakness. The aerial platform had a high plume capture rate, a quick turnaround time and high mobility thanks to the flexible ATV arrangement. The MPL also had a high rate of plume detection and the capability to scan through 2-D slices of the plume perpendicular to the plumes direction of travel. The TEOM, OP-FTIR, and UV-DOAS all had smaller plume detection rates and were mostly successful during higher wind speed conditions. The solar occultation FTIR was also able to detect the plume when the direction of the plume was correctly anticipated and cloud cover did not block the sun.

As the discussion above indicates, the Flyer measurement system was generally very successful in providing meaningful PM, metals, and organic gas emission factor data. The MPL-based and Flyer PM measurement systems provided PM-10 emission factors that were very comparable to each other for both OB and OD. The OB PM-10 emission factors for both systems were also close to published values. The variance from published values for OD PM-10 emission factors was not surprising due to local conditions affecting the amount of soil entrainment in OD plumes and the AP-42 Data Quality Rating of D for the PM-10 emission factor. ORS measurement system for gases were less successful in that the systems could not measure the target organic gases (i.e., benzene and naphthalene) and were not able to measure CO₂ for all plumes when CO was detected.

4.2 Implication for Future Research in Air Emission Characterization from OB/OD

There are technical gaps in the existing air emissions data from OB/OD and needs for additional scientific information in relation to the RCRA Subpart X permitting process. The following recent sources of information about research needs and data gaps for OB/OD will help guide the research team in proposing future work.

1. FY 2009 SERDP SON that addressed the needs for SERDP projects in air emission characterization from OB/OD.
2. The draft AP-42 Chapter 16 Background Document (2009).
3. Dr. Bill Mitchell's presentation at the 2010 Global Demilitarization Symposium and Exhibition, held at Tulsa, Oklahoma.

Some of the common technical gaps are as follows:

1. Metal emissions for OB and OD
2. SVOCs for OD
3. Particulate emissions, PM-2.5 and composition for OB, PM-10, PM-2.5, and composition for OD.
4. Soil covered detonation emissions
5. OD source configuration
6. Green house gas emissions
7. Rocket motor demilitarization.

In order to bridge the technical gaps identified above, there is a great need for research and development projects and supporting resources. However, the project team considers metal emission characterization, particulate matter emissions, and soil covered detonation emissions as the most pressing issues for the demilitarization community. The project team is ready to continue developing novel air emission measurement technologies and characterizing OB/OD emissions to provide answers to these pressing issues. The SERDP research will also complement both AP-42 Chapter 16 and DAC/China Lake's on-going joint efforts to develop additional emission factors from chamber studies and future field tests.

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Appendix A: USEPA Quality Assurance Project Plan



Imagine the result



Determination of Emission Factors from Open Burning and Open Detonation of Military Ordnance

Quality Assurance Project Plan
Category IV / Proof of Concept

Draft - Revision 0.1

Work Assignment 0-52

January 2010

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**Determination of Emission
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Military Ordnance**

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1. Project Description and Objectives

This Quality Assurance Project Plan (QAPP) provides guidance to personnel conducting emission testing under the U.S. Environmental Protection Agency (EPA) Work Assignment (WA) entitled "*Determination of Emission Factors from Open Burning and Open Detonation of Military Ordnance*", Contract Number EP-C-09-027, WA Number 0-52, Project Number RN99270.0052. This work is funded in part by an Intergovernmental Agreement (IA) which provides funding through the Strategic Environmental Research and Development Program (SERDP).

This WA is designed to develop and apply methods for sampling Open Burning/Open Detonation (OB/OD) of military ordnance in the field to characterize gaseous and particulate matter (PM) emissions for determination of emission factors of various target compounds. This project will use a novel measurement approach consisting of an aerial, balloon-borne instrument developed by EPA ("The Flyer").

This document covers in detail the background, objectives, technical approach, quality assurance (QA), and quality control (QC) aspects of data collection and analysis.

1.1 Background

U.S. Department of Defense (DOD) Installations, especially demilitarization facilities and Army Ammunition Plants (AAPs), have used Open Burning/Open Detonation (OB/OD) for a long time as a safe and economic means to dispose of propellants, explosives, and munitions. DOD installations are required to comply with the Resource Conservation and Recovery Act (RCRA) to operate OB/OD facilities. RCRA permits provide annual limits on the amount of energetic materials that can be disposed of at OB/OD facilities. The permit limitations are based on human health risk assessments that include risk estimates from airborne exposure to pollutants generated from OB/OD. These assessments use emission factors developed mostly from a limited number of tests on small scale OB/OD chambers, known as a "bang box." Emission factors developed from bang box tests have been challenged because of the potential differences between real world field situations and bang box test results. Some RCRA permit holders consider the permit conditions to be overly stringent because bang box data are too conservative and incomplete.

1.2 Objectives

This project has two objectives, both method development and measurement of process data. This project seeks to continue development of the "Flyer" as a measurement and sample collection device for both open burning and short term events such as OB/OD. The following sub-sections provide more information.

1.2.1 Method Development for the Flyer

The Flyer is a lightweight platform that is intended to support sampling, CEM, and data logging capabilities while being lofted by a tethered balloon within the downwind plume evolving from some burn event. Figure

1-1 illustrates the Flyer itself in an earlier configuration. As presented in this figure, it is configured with battery, pumps, NDIR carbon dioxide CEM, PM sampling by filter, PUF cartridge for semi-volatile organics, and a data logger for CO₂, flow, and temperature data. Figure 1-2 illustrates the Flyer in operation, lofted by a tethered balloon. The two ATVs with tether connections permit controlled positioning of the flyer within the plume. GPS measurements will be used to determine the position of the Flyer (altitude, coordinates) relative to the OB/OD event.

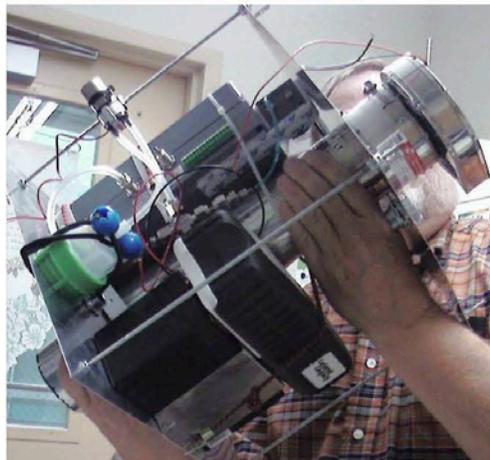


Figure 1-1. Flyer, version 1.



Figure 1-2. Lofted Flyer with ATV positioning.

1.3 Project Schedule

For the purposes of the planned measurements under this project, the Flyer will be configured with a carbon dioxide CEM; Summa canister for VOCs, PUF/XAD-2 resin/PUF sampling for semi-volatile organics, and filter for particulate matter. A small GPS (global positioning system) will be mounted on the Flyer for monitoring its location. Additionally, sophisticated electronics using the CO₂ signal will be used to “trigger” sampling events by opening sampling valves and initiating sampling pumps.

1.3.1 In-House Flyer Test Development and Target Compound Detection Limits

Trial runs will be performed at the EPA (RTP) facility to test the “Flyer” operability and determination of the target compounds detection limits. Two preliminary tests will be performed in RTP, NC to satisfy these needs prior to the project measurement sampling in the field. These will consist of a burn hut test in January (preliminary schedule) in which the Flyer will be suspended and operating in the enclosed burn hut during a combustion test. The primary purpose of this test is to examine the hardware functioning such as the concentration-triggered sampling valves. The second test will consist of an actual sampling event with the Flyer lofted in the plume from a forest fire or sampling ambient air mimicking the actual OB/OD test.

This test will examine any hardware modifications resulting from the burn hut test and collect samples that will be used to examine detection limits. None of these data are intended for publication.

Preliminary tests are being done on sorbent contamination levels, ambient air levels of target analytes from proposed sampling media, and breakthrough tests. This will also include spike testing of Summa canisters.

1.3.2 Field Measurements

The balloon-lofted Flyer will be used to collect data and samples during the open burn (OB) and open detonation (OD) of military ordnance at the Tooele Army Depot, Tooele County, Utah in March of 2010. Figure 1-3 provides a map of the area.

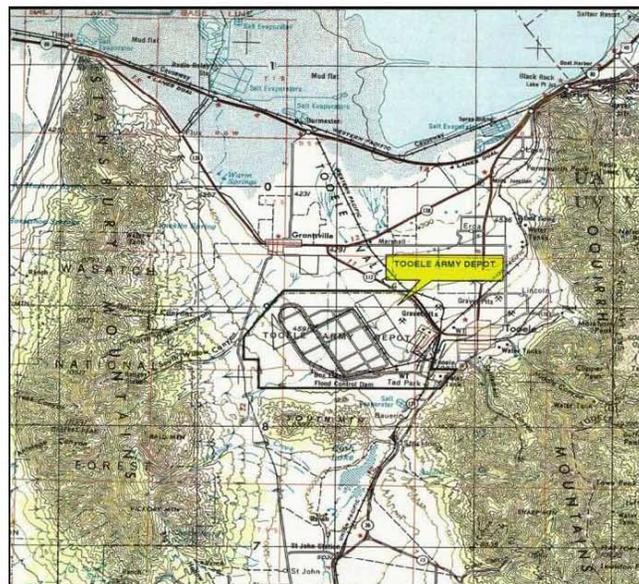


Figure 1-3. Map Locating Tooele Army Depot.

Figure 1-4 provides a close-up map of the Test Range which consists of an indoor facility, bunkers, a detonation test range, and a concrete pad for open burning tests. The elevation at the Tooele test range is about 5500 feet above sea level. The Test Range consists of a concrete pad (~25×25 meter, inside the small red and green circles) for the OB tests and a gravel/sand field (~100×50 meter) for the OD tests (small

gray rectangle). The OB and the OD tests are video monitored and recorded from the indoor facility/bunker (#1376) on Figure 1-4.

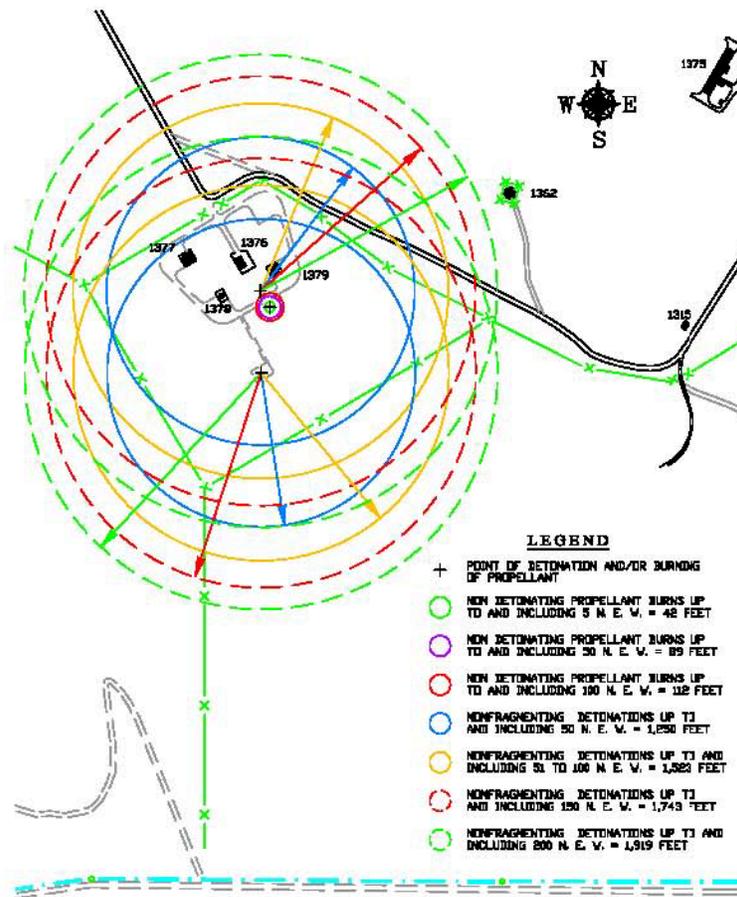


Figure 1-4. Tooele Test Facility Map.

Meteorological data such as wind speed, wind direction, and temperature will be collected from the Salt Lake City National Weather Service, www.noaa.gov, and www.accuweather.com, which gives an hourly forecast. In addition, the Army Depot has two local weather stations that measure wind speed and wind direction at ground level. The weather forecast and the actual weather conditions have been shown to be in good agreement. The wind direction is mostly stable in the mornings and in the afternoons while during midday the winds are unstable i.e., fast changes in the wind direction. The predominant wind direction is from the north-northwest. During the month of March the temperature is between 20 to 60 °F (-6 to 16°C). The Army Depot local wind data will be used to calculate the sampling module positioning in addition to personnel safety. The maximum allowed wind speed for performing the detonations and burns are 15 MPH (6.7 m/s) with gusts up to 25 MPH (11 m/s). In addition, the minimum visibilities for detonations are 1 mile with not less than 2,000 ft of ceiling (cloud cover) for detonations.

The proposed test matrix and schedule in this program are subject to changes in time and scope by the EPA WA Manager due to budget constraints or facility approval. Table 1-1 details the proposed schedule for this project.

Table 1-1. Test Schedule.

Task	Start Date	Planned Completion
QAPP	December 20, 2009	January 15, 2010
In-House Flyer Test development and Target Compounds Detection Limits	January 15, 2010	February 26, 2010
Tooele sampling campaign	March 8, 2010 (site preparation) and March 15 (actual sampling)	March 26, 2010
Data Analysis and Reporting		Upon Availability of the data

2. Project Organization

The organizational chart for this project is shown in Figure 2-1. The roles and responsibilities of the project personnel are discussed in the following paragraphs. In addition, contact information is also provided.

EPA WA Manager, Dr. Brian Gullett: Dr. Gullett has overall project responsibility. He will direct the project's technical aspects and will be responsible for maintaining project budgets. Dr. Gullett will coordinate with EPA Quality Assurance (QA), EPA management, and with the ARCADIS WA Leader (WAL). He will schedule meetings with the ARCADIS WA Leader (WAL) to discuss issues related to the work assignment and the necessary corrective actions to be taken. He has the authority to request a stop work order be placed on the work assignment by the Contract Officer for safety or quality control reasons.

Phone: 919.541.1534

E-mail: gullett.brian@epa.gov

EPA QA Representative, Robert Wright: The EPA QA Representative will be responsible for reviewing and approving this QAPP. In addition, this project is subject to audits by EPA QA. Mr. Wright is responsible for coordinating any EPA audits.

Phone: 919.541.5510

E-mail: wright.robert@epa.gov

EPA Electronics Engineer, Chris Pressley: Mr. Pressley will be responsible for Flyer instrument wiring and connections, and data logging.

Phone: 919.541.1363

E-mail: pressley.chris@epa.gov

Post-doctoral Fellow of National Research Council, Johanna Aurell: Dr. Aurell will be helping Dr. Gullett for all the technical aspects of the projects, including the design of the test matrix, participation in the sampling campaign, and data reporting at the discretion of the EPA WAM. Dr. Aurell will be responsible for sampling and data collection.

Phone: 919.541.5355

E-mail: Aurell.Johanna@epa.gov

EPA Organic Laboratory Manager, Dennis Tabor: Mr. Tabor will be responsible for the analytical work associated with the project. Mr. Tabor will review any samples sent to an outside laboratory for completeness.

Phone: 919.541.2686



**Determination of Emission
Factors from Open Burning
and Open Detonation of
Military Ordnance**

Version 0.1

Date: January 2010

E-mail: Tabor.dennis@epa.gov

ARCADIS WAL, Dr. Dahman Touati: The ARCADIS WAL is responsible for preparing project deliverables and managing the WA. He will assist in analytical data reduction, validation, and reporting. He will ensure the project meets scheduled milestones and stays within the budgetary constraints agreed upon by EPA. The WAL is responsible for communicating any delays in scheduling or changes in cost to the EPA WA Manager as soon as possible.

Phone: 919.541.3662

E-mail: dtouati@arcadis-us.com

ARCADIS QA Officer, Laura Nessley: The ARCADIS QA Officer is responsible for reviewing and approving this QAPP. She will ensure that the QAPP is implemented by performing routine assessments. At this time, no planned internal systems or performance audits are scheduled; however, Ms. Nessley performs random internal audits on a regular basis on EPA/Onsite Laboratory Support Projects. In addition, any report prepared for EPA will be reviewed by Ms. Nessley and at least 10% of the reported data will be validated back to the raw data sheets, notebooks, etc. Ms. Nessley will communicate regularly with the EPA QA Manager to coordinate any planned audits.

Phone: 919.328.5588

E-mail: lnessely@arcadis-us.com

ARCADIS Safety Officer, Jerry Revis: Mr. Revis will be responsible for ensuring that this project is carried out in accordance with all permit and EPA safety requirements. He will also ensure that anyone working on the project has fulfilled all of the safety training requirements.

Phone: 919.328.5573

E-mail: jrevis@arcadis-us.com

ARCADIS, David F. Natschke: Mr. Natschke is an ARCADIS senior chemist. He is responsible for the drafting and finalization of this quality assurance project plan. As directed by the WAL, he may perform other duties under this work assignment.

Phone: (919) 541-2347

E-mail: dnatschke@arcadis-us.com

A team of ARCADIS technicians will assist the WAL with operation, sampling, and maintenance of facility equipment.

2-2

ARCADIS, Donnie Gillis: Mr. Gillis, in concert with the project engineer and Mr. Terll, will be responsible for and will assist the WAL in all aspects of the project.

Phone: (919) 541-1066
 E-mail: dgillis@arcadis-us.com

ARCADIS, Steve Terll: Mr. Terll, in concert with the project engineer and Mr. Gillis, will be responsible for assisting in the Flyer maneuvering for sample collection and will assist the WAL in all aspects of the project.

Phone: (919) 541-4315
 E-mail: sterll@arcadis-us.com

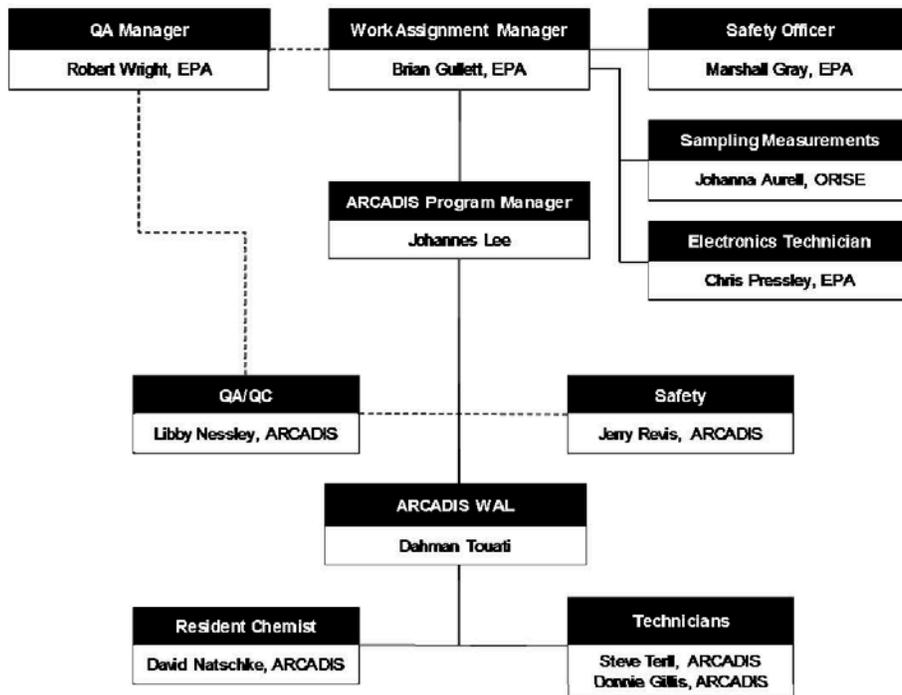


Figure 2-1. Organization Chart.

3. Experimental Approach

3.1 Sampling Approach

The Flyer, Figure 1-1, is a loftable, instrument-bearing platform for the collection of batch gas and particle samples from ambient air or plumes, the collection of permanent gas concentrations via continuous emission monitors, and the logging of data. It includes programmable logic control hardware that may, for example, enable sampling only when CEM data indicates that the Flyer is located within a plume. Power for the instruments is provided by replaceable, rechargeable battery sources.

Previous work has shown that the mass of the Flyer (ca. 10 kg) is within the lofting capabilities (~15 kg at sea level) of the Kingfisher (K13N) 13×10.3 foot-diameter helium balloon, Figure 1-2. The balloon is tethered using Spectra line to a pair of ATVs equipped with electrically powered winches. The combination of two ATVs and two tethers permit the positioning of the balloon, and therefore the Flyer, at a specific location and height downwind of a sampling event. Calculations from wind direction and speed permit calculation of the target location and elevation. A third potential tether and winch will be used to provide a third, vertical dimension for the Flyer below the balloon.

The purpose of the planned Tooele Army Depot sampling event is to demonstrate the Flyer sampling technology for determination of emission factors from OB/OD events. This will be accomplished by collecting plume samples to calculate concentration data for selected analytes. A limited set of target analytes, selected from those for which emission factors exist and for which there is a reasonable degree of confidence, is sufficient to satisfy the technology demonstration purposes of this project. The target analytes for this project will be benzene, naphthalene, lead, and total particulate matter. These analytes represent a range of anticipated OB/OD products and, hence, represent a broad range of sampling methods/equipment. The VOC, semi-volatile, and filter samples will be analyzed to calculate concentrations for these analytes. The CO₂ CEM data will be used to calculate a co-sampled carbon concentration, which will permit conversion of analyte concentrations to emission factors by a carbon balance method. In this method, the ratio of the sampled target analyte concentration to the total sampled carbon (as CO₂) is related back to the initial ordnance weight through knowledge of the carbon concentration in the original ordnance and the assumption of 100% oxidation of the carbon.

As described in section 1.2.1, the Flyer is being configured for this project with a carbon dioxide CEM, VOC sampler with a Summa canister, semi-volatile sampling with a sandwiched PUF/XAD-2/PUF sampler, particulate sampling by filter, and temperature plus relative humidity using a HOBO (U12-013) sensor with data logging. CEM data are logged to an on-board HOBO U12-006 unit.

During the March sampling event, samples will be collected from both OB and OD of M1 propellant and trinitrotoluene (TNT), respectively. Table 3-1 provides the composition of these materials, while Table 3-2 provides available emission factors for the target analytes.

Table 3-1. Composition of OB and OD Ordnance

Material	Mass %	Composition	
M1	84	Nitrocellulose	$C_8H_7(NO_2)_3O_5$
	9	2,4-dinitrotoluen (DNT)	$C_6H_3(CH_3)(NO_2)_2$
	5	Dibutyl phthalate (plasticizer)	$C_{16}H_{22}O_4$
	1	Diphenylamine	$(C_6H_5)_2NH$
	1	Lead carbonate	$PbCO_3$
TNT	100	Trinitrotoluene	$C_7H_5N_3O_6$

Table 3-2. Emission Factors.¹

Analyte	Units	TNT, OD	M1 propellant, OB
CO ₂	lb/lb C	3.5	3.6
Naphthalene	lb/lb NEW	$1.3 \cdot 10^{-6}$	$1.9 \cdot 10^{-8}$
Pb	lb/lb NEW	NA	0.0078 [†]
PM ₁₀	lb/lb NEW	7.2	0.0069
Benzene	lb/lb C	$2.6 \cdot 10^{-4}$	$1.4 \cdot 10^{-5}$

lb/lb C pound per pound carbon

lb/lb NEW pound per pound net explosive weight

NA not available

[†] Calculated from Table 3-1 composition data assuming 100% release

Sampling will occur after each of single or multiple (in series) open burn and open detonation tests. Each series of tests (whether single or multiple) is defined as an event. The number of events per sample will be determined by pre-test, CO₂-only measurement trials designed to understand what level of pollutants can be anticipated and at what rate from a single OB and single OD trial test. The CO₂ concentration will be used as a surrogate measure of the plume's pollutant concentration. It is almost certain that OD will be sampled after serial detonations in order to achieve higher pollutant concentrations; OB is less certain to be in series as sufficient concentrations may be observed during single burn events.

For each of the OB and OD scenarios, a five day sampling campaign with morning and afternoon events, is planned as the maximum number of sampling periods. For the first week, five days of morning and

¹ AP-42 Draft Chapter 16 "Emission Factors for Demilitarization Processes: Open Burning and Open Air Detonation"

afternoon tests will result in nine OB events (the first day will include background sampling and one event sampling). Similarly, the second week will result in five days of morning and afternoon OD events for a total of nine events. For each target analyte, five replicate samples will be targeted, although more are desirable. Each target analyte is measured by a different instrument that can be moved on or off the Flyer as needed. The number of analytes that can be sampled simultaneously will be determined by instrument weight restrictions, battery life considerations, and Flyer performance. Hence, the maximum number of tests that a single analyte will be sampled is nine for OB and nine for OD, plus background and blank samples. The minimum desirable tests for a single analyte is five for OB and five for OD, plus background and blank samples.

3.2 Analytes and Process Measurements

The following list describes the critical measurements:

- Benzene
- Naphthalene
- Carbon dioxide
- Total solid particulate
- Lead
- Sampling flow rates

Table 3-3 presents the planned sampling and analysis methods

Table 3-3. Sampling and Analysis Methods.

Target Compound	Sampling Method	Sampling Rate	Analysis
Benzene	TO-15 Summa	0.6-3 L/min	GC/LRMS
Naphthalene	TO-15, Summa	0.6-3 L/min	GC/LRMS
Naphthalene	Modified TO-13, PUF/XAD-2/PUF	250 L/min.	GC/LRMS
PM	Filter	15 L/min	Analytical Balance
Lead	Filter	15 L/min	Compendium Method IO-3.3, EDXRF
Carbon dioxide	CEM	Every second	NDIR CEM
Carbon dioxide	EPA Method 25C, Summa	0.6-3 L/min	GC
Temperature			HOBO U12-013
Relative humidity			HOBO U12-013

3.3 Test Specific Sampling Procedures

3.3.1 Open Burning

The balloon and Flyer will be prepositioned downwind of the burn site with the aid of small release balloons and smoke grenades. Two ATVs with electric winches and tethers will be used to anchor and maneuver the balloon. The ATVs and the balloon, as well as all personnel, will be located outside the safety stand-off distance. Each ATV will have a driver. If a vertical tether is used, the third tether will also have an attendant. The M1 propellant will be ignited and the ATVs will be adjusted to maneuver the balloon into the plume, guided by visual observation and a high visibility light which is activated by the CO₂ trigger level.

Optimal locations for plume collection will be calculated prior to the event using the Open Burn Open Detonation Model (OBODM) computer model (Reference) and local meteorological conditions. During the week of March 8th, an initial, single, "pre-sampling" M1 burn will be used to verify the model output and to determine effective burn duration and the CO₂ concentration-time profile. This sampling may alternatively use a smaller Kingfisher balloon which has a rated lift of 8 lbs. The larger balloon was tested and found to have a practical lift of 43 lbs versus its rated lift of 34 lbs. When also accounting for a 3%/1000 ft altitude penalty, we anticipate a 6.8 lb practical lift for the small Kingfisher which will enable us to easily loft the 2.2 lb LI-COR Biosciences LI-820 CO₂ monitor and its 2 lb pump/filter and battery. This burn will determine the frequency of burn ignitions and the optimal standoff distance. If the CO₂ profile is short in time, then the period between ignitions should be short. If the profile is sustained, then a longer period is mandated. These profile data also need to be reconciled with required standoff distances and optimal post-ignition positioning. If sufficient concentrations are possible outside of the safety arc, then successive ignitions will not require personnel retreat beyond the safety arc. Successful plume location and pollutant concentrations will be determined by examination of the HOBO data of logged CO₂ concentration and analysis of the CO₂ and benzene (during the actual testing) concentrations in the Summa canisters. These canisters will be sent via overnight courier to an analytical laboratory in California for analysis. These data will provide feedback on our ability to successfully maneuver into the plume and our mass collection rate of pollutants, complementing our CO₂ data. On-board GPS measurements will be used to determine the position of the Flyer (altitude, coordinates) relative to the OB/OD event and, with CO₂ measurements, be used to determine the efficacy of the OBODM output.

The likely scenario will include successive burns, timed to insure high concentrations within the plume, but with enough time to maneuver the Flyer for optimal plume capture. Up to four burns in series with a charge of 200 lb each of M1 propellant per burn are envisioned for each event, for a total of 1600 lbs per day (two events) maximum. At the time of this writing, the pans were being constructed with a 100 lb capacity, suggesting that two co-located pans might be ignited simultaneously to achieve the 200 lb burn. Each burn will have about 5-10 minutes between burn ignitions, depending on the plume duration. The estimated sampling time is up to 10 minutes per burn. To the extent possible, the burn pans will be aligned collinearly

with the burn vector to minimize Flyer repositioning. The number of ignitions will depend on the calculated amount necessary to exceed the analyte detection limit, judged from historical emission factors and the rate and amount of CO₂ collected at the site during the pre-test trial burn. Upon detection of sufficiently elevated carbon dioxide levels above background, determined in part by the single pre-test and small balloon CO₂ measurements, a trigger circuit will initiate VOC and semi-volatile sampling.

It is anticipated that personnel will always be outside of the safety range during ignition and burning. Upon completion of the event sampling (one to four burns), the Flyer will be brought down. Data will be downloaded from the on-board data logger. The Summa canister will be removed, sealed, and shipped to the laboratory with its chain of custody sheet (COC). The Semi-volatile sampling media sandwich will be removed, logged and preserved before shipment to RTP. The filter sample will be logged and its COC will be shipped to an outside laboratory for analysis by EDXRF.

Table 3-4 presents a test plan for the open burning tests. Figure 3-1 illustrates the open burn site with its concrete pad. Figure 3-2 presents an open burn pan. These pans are re-usable and constructed of sheet steel.

Table 3-4. Open Burn Test Plan.

Date	M1 burn	VOC, Summa canister	Semi-volatiles, PUF/XAD-2/PUF	Pb and PM	CO ₂
3/15/2010	4*200 lb	Field blank	Field blank	Field blank	Background (upwind)
		Background (upwind)	Background (upwind)	Background (upwind)	Background (upwind)
		X	X	X	X
3/16/2010	4*200 lb	X	X	X	X
	4*200 lb	X	X	X	X
3/17/2010	4*200 lb	X	X	X	X
	4*200 lb	X	X	X	X
3/18/2010	4*200 lb	X	X	X	X
	4*200 lb	X	X	X	X
3/19/2010	4*200 lb	X	X	X	X
	4*200 lb	X	X	X	X
3/20/2010	spare				
3/21/2010	spare				

Total of 7200 lbs M1

X = Analyte sampling. Number of analytes sampled during each run will be determined by on-site-determined concentrations and sampling times.



Figure 3-1. Open Burn Site



Figure 3-1. Open Burn Pan (TNT flakes shown).

Sampling time estimates for each target analyte used literature emission factors, ambient air background concentrations, and our preliminary analyses of the contaminant level of the sampling media. Our primary focus here is detection of naphthalene and benzene. The emission factor values were used in OBODM to predict plume concentrations. Together with our method sampling rates, analyte mass could be determined. These mass values were then compared to the ambient air levels and method detection limits. The sampling times necessary to equal or exceed ambient air levels and/or method detection limits were determined.

The Tooele naphthalene concentration is cited³ as $0.006 \mu\text{g}/\text{m}^3$. Based on literature values for emission factors (Table 3-2), OBODM was used to estimate the plume concentration at the Flyer under anticipated sampling conditions (200 lb of M1, 35 m from the burn, height of 15-20 m, and a wind speed of 2 m/s). Since the literature-cited emission factor for naphthalene was determined by sampling semi-volatiles on a quartz-fiber filter, it only reflects the particulate phase and misses the volatile phase.¹ A recent ambient air study² showed that 20% of the ambient air concentration of naphthalene is found in the particulate phase. Hence, the OBODM-predicted plume concentration was increased by 5X to $0.025 \mu\text{g}/\text{m}^3$ as a more accurate prediction of the time-averaged plume concentration from 0 to 2 min (the minimal OB plume sampling time that we reasonably anticipate we can sample). Unfortunately, our preliminary tests for the PUF/XAD method have shown that the naphthalene sampling media, XAD-2, is contaminated with naphthalene even after cleanup, confounding distinctions with sampled emissions. Our current studies have shown 15 ng naphthalene/g XAD-2, meaning that each field sample would have a contaminant concentration of $0.3 \mu\text{g}$ on the 20 g of XAD-2. To obtain an equal amount of naphthalene from the M1 burn as from the XAD contamination we need to sample for 48 minutes at the OBODM-predicted 2 min time-average concentration, or 24 burns. We anticipate considerable improvements on this sampling requirement through our current efforts to clean the XAD-2 of contaminants. We also believe that more than 2 min of effective sampling can be done on each open burn. The PUF/XAD method will also be complemented by the Summa canister method which may show greater ease of detection.

Use of the emission factor for benzene (Table 3-2) in OBODM shows that the plume concentration easily exceeds the ambient air level of $0.55 \mu\text{g}/\text{m}^3$ (2002 NATA, Ref. 3). The ratio of sampled emissions and background emissions would be 2/1 for benzene when sampling from 0 to 2 min after ignition. Hence, benzene poses less of a sampling time (volume) challenge than naphthalene.

Table 3-5. Required sampling time to surpass anticipated ambient background concentrations and method detection levels during OB. 200 lb of M1 (one charge), 35 meter from the burn, height of 15-20 m, and a wind speed of 2 m/s.

Target Compound: sampling method	ΔTime-average concentration in the plume (2 min, μg/m ³)	ΔTime-average concentration in the plume (6 min, μg/m ³)	Ambient air conc. (μg/m ³)	XAD conc. (μg/sample)	Required sampling time (min) ¹ within the first...	
					2 min of the burn	6 min of the burn
Benzene: Summa canister	2.9	1	0.55	NA	2	2
Naphthalene: Summa canister	0.025	0.01	0.006	NA	1-2	1-6
Naphthalene: PUF/XAD-2/PUF	0.025	0.01	0.006	0.3	48	120
Lead: filter	TBD	TBD	0	TNA	TBD	TBD
CO₂: NDIR CEM	330 ppm	110 ppm	~ 390 ppm	NA	NA	NA

*1. The sampling time range for sampling with summa canister is dependent on the sampling flow rate, 0.0006-0.003 m³/min.

TBD – to be determined

¹ Development of methodology and technology for identifying and quantifying emission products from open burning and open detonation thermal treatment method: Volume 1 – Test Summary. Maintenance management Division, Demilitarization and Technology Branch. 1992.

² Jun He, Rajasekhar Balasubramanian. Semi-volatile organic compounds (SVOC) in ambient air and rainwater in a tropical environment: Concentrations and temporal and seasonal trends. Chemosphere, in press, 2009.

³ <http://www.epa.gov/ttn/atw/hata2002/tables.html#table1>

3.3.2 Open Detonation

The balloon and Flyer will be pre-positioned downwind of the detonation site. The downwind direction will be determined by the release of small balloons and smoke grenades. Two ATVs with electric winches and tethers will be used to anchor and maneuver the balloon. The ATVs and the ground-fixed balloon/Flyer will likely be located inside the safety stand-off distance, each behind protective bunkers. All personnel will be outside of the stand-off distance and behind a protective bunker. The balloon/Flyer will be released from its ground-based shelter using either wireless (2.4GHz) or wired remote control. When the balloon is no longer in danger of being damaged from the shrapnel and shock wave of the last detonation the balloon will be released to fly up into position. Once deployed, the balloon will be maneuvered by retracting and extending the electric winches via remote control. Additional maneuvering can be achieved by manning the ATVs with drivers but this will only be done after the required safety period for personnel has expired and/or given permission by the range control officer. To keep the balloon/Flyer's location optimized in the plume personnel will use visual observation and a high-CO₂ flashing light mounted on the Flyer.

An initial, single, "pre-sampling" detonation will be used to determine effective shrapnel zones (for the equipment), plume duration, and the CO₂ concentration-time profile. This detonation will determine the frequency of detonations and the optimal standoff distance. If the CO₂ profile is short in time, then the period between ignitions should be short. If the profile is sustained, then a longer period is mandated. Modeling, however, predicts rapid dispersion of the pollutants, requiring detonations in rapid succession. This will ensure high concentrations within the plume, but with enough time to maneuver the Flyer for optimal plume capture. This may mean about 5-15 seconds between detonations. The number of ignitions will depend on the calculated amount necessary to exceed the analyte detection limit, judged from historical emission factors and the rate and amount of CO₂ collected at the site.

On each morning or afternoon of sampling, up to three detonations in series with a charge of 200 lb each of TNT will occur, for a total of 1,200 lbs per day, maximum. Each detonation will have about 5-15 seconds between initiation to maximize the plume concentration while minimizing the safety standoff distance (through minimizing the charge size).

Multiple morning and afternoon sampling events consisting of multiple detonations, may be used to create a single, composite sample. This single sample will be created by reusing the same sorbent media during multiple events. The primary indicator of required composite samples will be the CO₂ mass collected and the published emission factors. Upon completion of sampling, the Flyer will be brought down for downloading the on-board data logger. The Summa canister will be removed, sealed, and shipped to the laboratory with its chain of custody sheet (COC). The Semi-volatile sampling media sandwich will be removed, logged and preserved before shipment to RTP. The filter sample will be logged and its COC will be shipped to a commercial laboratory for determination of PM and lead.

Table 3-6 presents a test plan for the open detonation tests.

Table 3-6. Test Plan for Open Detonation Sampling.

Date	TNT	VOC, Summa canister	Semi-volatiles, PUF/XAD-2/PUF	PM	CO2
3/22/2010	3*200 lb	Field blank	Field blank	Field blank	Background (upwind)
		Background (upwind)	Background (upwind)	Background (upwind)	Background (upwind)
		X	X	X	X
3/23/2010	3*200 lb	X	X	X	X
	3*200 lb	X	X	X	X
3/24/2010	3*200 lb	X	X	X	X
	3*200 lb	X	X	X	X
3/25/2010	3*200 lb	X	X	X	X
	3*200 lb	X	X	X	X
3/26/2010	3*200 lb	X	X	X	X
	3*200 lb	X	X	X	X
3/27/2010	spare				

5400 lbs TNT total. Three detonations in series is limited by the current pad size. Period is 5 to 15 s between detonations with 15 s preferable by the Range personnel. Each detonation is 65 ft apart and the 200 lb TNT safety distance is 1,919 ft (100 lb is 1,743 ft). Charges will be placed collinearly with the wind vector, to the extent predictable.

As with OB, sampling time estimates for each target analyte used literature emission factors and ambient air background concentrations as well as our preliminary analyses of the contaminant level of the sampling media. Table 3-7 shows that only the PUF/XAD/PUF method for naphthalene may require multiple 200 lb detonations to reach desired concentration levels.

Table 3-7. Required sampling time to surpass anticipated ambient background concentrations and method detection levels during OD. 200 lb of TNT (one charge), 61-100 m from the detonation, and wind speed of 2 m/s.

Target compound: Sampling Method	ΔTime-average concentration in the plume (2 min, µg/m ³)	ΔTime-average concentration in the plume (4 min, µg/m ³)	Ambient air conc. (µg/m ³)	XAD conc. (µg/sample)	Required sampling time (min) within the first...	
					2 min of the burn	4 min of the burn
Benzene: Summa canister	4.4-2.1	2.2-1.1	0.55	NA	1	1
Naphthalene: Summa canister	0.3-0.15	0.15-0.075	0.006	NA	1	1
Naphthalene: PUF/XAD-2/PUF	0.3-0.15	0.15-0.075	0.006	0.3	4-8	8-16
CO₂: NDIR CEM	65-31 ppm	16-8 ppm	~ 390 ppm	NA	NA	NA

3.4 Sampling methods and other critical measurements

3.4.1 Carbon Dioxide by NDIR CEM

Carbon dioxide measurements will be performed using LI-COR Biosciences LI-820 non-dispersive infrared (NDIR)-based CEMs mounted on the Flyer. This unit is configured with the optional 14 cm optical bench, giving it an analytical range of 0-2,000 ppm with an accuracy specification of <2.5% of reading. Carbon dioxide measurements are expected to vary between ~380-750 ppm. Signal averaging can be adjusted from 0-20 seconds per reading. The LI-COR Biosciences LI-820 CEM is equipped with a programmable alarm output. This output is capable of controlling solenoids as well as visual and audible alarms. Based upon preliminary tests (prior to March 15, 2010) this alarm circuit will be programmed to turn on when above ambient levels of carbon dioxide, i.e., the Flyer is within the plume. This alarm circuit will be used to turn on pumps and open solenoid valves, as described below in section 4.2. The LI-COR LI-820 is equipped with adjustable high and low alarm values and for each of these a "dead band" value can be chosen i.e., the upper alarm is activated at the chosen value and remains activated until the CO₂ concentration drops below the set dead band value.

3.4.2 Summa Canister Sampling for VOCs and Carbon Dioxide

Volatile organics will be sampled via Method TO-15 "Determination of Volatile Organic Compounds (VOCs) in Air collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)." <http://www.epa.gov/ttn/amtic/files/ambient/airtox/to-15r.pdf>. Sampling for VOCs will be accomplished using laboratory-supplied 6 L Summa canisters. This canister will be equipped with a pressure gauge, manual valve, critical orifice assembly (COA) and a solenoid valve, the latter controlled by the carbon dioxide trigger circuit. Columbia Analytical Services, 2655 Park Center Drive, Suite A Simi Valley, CA, 93065 will provide summa canisters with a 12V valve with orifice and filter already put together. The laboratory will configure and calibrate the critical orifice assemblies and ship them to the field along with the Summa canisters. Separate valve/orifice/filter combination for an anticipated range of 1, 2, 6, and 10 minutes are anticipated. This range of sampling durations are meant to sample the short, several minute peak concentration plumes and longer, multi-minute peak concentration plumes. The shorter sampling periods risk representativeness and the longer sampling periods risk sample dilution and detectability. These sampling rates will likely be different for OB and OD experiments, and for the number of plumes to be collected as a single sample.

The Summa canister will be hung from the bottom of the Flyer and will have its solenoid valve controlled by the LI-COR LI-820's alarm circuit. At the beginning of a sample collection, the gauge will be checked to ensure no leakage has occurred; then the manual valve will be opened. When the LI-COR LI-820 measures elevated levels of carbon dioxide, its alarm circuit will enable a solid state relay, which will open the canister's solenoid valve and sampling will occur at the critical orifice's calibrated flow rate. The solenoid valve will close and sampling will cease when carbon dioxide readings return to ambient levels. Following the end of sampling, the manual valve will be closed, the canister will be dismounted from the Flyer, the COA will be removed, and the canister will be returned to its shipping container.

Each Summa canister sample will also be used for analysis of carbon dioxide by GC, utilizing EPA method 25C. Method 25C also specifies gas sample collection by evacuated cylinder.

3.4.3 Semi-volatile sampling

In a similar manner, semi-volatile sampling will occur using a PUF/XAD-2 resin/PUF sorbent sandwich. This sandwich will be delivered to the site already mounted in a glass tube with clamping flange. The sandwich will be prepared for sampling by removing it from its shipping container, removing the aluminum foil ends, and mounting it on to a BLDC blower. Semi-volatile sampling will be performed using a BLDC Low-Voltage Blower for a nominal sampling rate of 0.25 m³/min. The blower will be controlled by the carbon dioxide alarm circuit. Flow rate will be measured by pressure differential across a calibrated venturi. A venturi consists of a carefully calculated and constructed constrictor. As used here, it will be mounted on the outlet

of the semi-volatile sampler. A venturi has the property that fluid pressure through a constricted section of pipe is reduced. The fluid velocity must increase through the constriction to satisfy the equation of continuity, while its pressure must decrease due to conservation of energy. As such, a measurement of ΔP between the venturi's inlet and constricted diameter body will measure this pressure drop and that data may be used to calculate flow rate. In practice, a calibration curve is developed from ΔP and actual flow measurements. The voltage equivalent to this pressure differential will be recorded on the HOBO external event logger. The APPCD Metrology lab will perform these measurements using the venturi's matched transducer and a Roots meter. Following sampling, the sandwich will be removed from the Flyer, the ends will be sealed with clean aluminum foil, it will be returned to its shipping container, and stored at 4°C until shipped to the laboratory.

Naphthalene is being sampled by the PUF/XAD method, in addition to the Summa canister method, since the Summa method has uncertain recoveries for less volatile compounds. The PUF/XAD sorbent method will also allow us to look for other semivolatiles, including PAHs.

3.4.4 Particulate matter sampling

Particulate matter sampling will occur using a 47 mm tared Teflon filter. The filters will be shipped to the site pre-tared and mounted in sealed cassettes. The seals will be removed and the cassette will be connected to the sample pump. PM sampling will be performed via an SKC Leland Legacy Sample pump with a constant airflow of 15 l/min. The internal flow sensor measures flow directly and acts as a secondary standard to constantly maintain the set flow. The volume display is continually updated, based on corrected flow rate multiplied by sampling time. The display presents the pump serial number, pump software revision level, flow rate, volume, temperature, atmospheric pressure, time of day, run time, and pump status, i.e., hold and run as well as Setup information. The pump will be controlled by the carbon dioxide alarm circuit. Following sampling the cassette will be dismounted. The inlet and outlet of the cassette will have their seals re-installed. A gel band will also be installed as further insurance against seals opening during preservation and shipment. The sealed cassette will be placed in a ZipLock bag pre-loaded with desiccant.

It should be noted that detonations occur on soil surfaces and, as such, the plume includes significant soil particulate matter. This is reflected in Table 3-2 where the open detonation PM_{10} emission factor is much larger than the charge weight. One grab sample will be collected from soil at the OD site using a 20 mL scintillation vial. The vial will be sealed with a non-metallic threaded cap and stored for shipment to the laboratory.

3.4.5 Sampling Time

Sample times for the Summa canister and particulate filter are not separately recorded. Sampling time for the Summa canister, semi-volatile sorbent sandwich, and particulate filter are all based upon the same carbon dioxide switched alarm. They are, therefore, identical (up to the point where the summa canister has been filled to ambient pressure). Sample time is, therefore, based upon the semi-volatile sampling pump where voltages from the venturi's differential pressure measurement will be recorded on the HOBO external event data logger.

3.5 List of Samples

- Summa Canisters, 6 L, with calibrated critical orifice assembly hardware
- PUF/XAD-2 resin/PUF will be prepared from cleaned PUF plus manufacturer-cleaned XAD-2 resin. They will be packed in the glass samplers and sealed with clean aluminum foil. Cleaned PUF consists of as-received PUF that is solvent cleaned using sequential toluene and dichloromethane elution. It is dried under a flowing nitrogen stream prior to use.
- Filter, Teflon, 47 mm, tared.
- Grab samples from the OD soil particulate are collected in a 20 mL scintillation vial with non-metallic caps. Cap to be sealed with vinyl or electrical tape after sample collection. An OSHA-21 seal is wrapped lengthwise after sample collection.

3.6 Sample Preservation Requirements

- Filter samples are preserved by storage under desiccant.
- Soil grab samples are stored in a sealed glass vial.
- Samples collected on PUF/XAD-2/PUF will have the ends sealed with new aluminum foil and will be refrigerated after collection. Samples must be shipped and extracted within 14 days of sampling.
- VOC samples must be analyzed within 14 days of collection.

3.7 Numbering Method - TBD

All samples and field blanks will be coded with a mixed alphanumeric code of the form:

TADAZ03__10__:__:__

The three character prefix is constant and specifies collection at the Tooele Army Depot

The 4th character (A) specifies the sampling medium and will be either F, S, or V, where

- F Filter
- S Semi-volatile sorbent pack
- V Volatiles collected by Summa Canister

The 5th character (Z) specifies samples versus QA and will be either B, S, U, where

- B Field blank sample
- S Sample
- U Upwind sample

The next 6 characters will be a numeric string to define the date of collection. Of those 6, the first 2 will be "03" and the last 2 will be "10" for this study, defining the month and year of this study

The final 8 characters will specify the start time for sample collection (the time the balloon is lofted) in hours:minutes:seconds.

For each sample a chain of custody sheet will be generated. For a sample collected in a Summa canister, this sheet will also record the canister's associated serial number and bar code. For a particulate sample, the COC will also record the filter numbering from the laboratory performing the conditioning and taring.

3.8 Packing and Shipping

- Summa canisters are shipped to and from the field in boxes². The critical orifice assemblies are individually wrapped in bubble wrap and shipped with the associated canister. Summa canisters are shipped overnight for morning delivery to the contract laboratory.
- Samples collected on PUF/XAD-2/PUF are shipped overnight in insulated chests with chilled refrigerator packs.

² www.caslab.com "Canister Sampling Instructions"

- Sampled filters are returned to the SKC cassettes and sealed with the Omega gel bands. The cassettes are marked with the sampling information. The cassettes are stored in Zip-Lock bags with desiccant. Filter samples are shipped to the laboratory separate from bulk samples.
- Grab samples in scintillation vials are shipped to the laboratory separate from air samples.
- FedEx procedures for summaries - TBD

4. MEASUREMENT AND ANALYTICAL PROTOCOLS

Critical measurements are: CO₂, Pb, Total PM, benzene, naphthalene, sample flowrates, and times. This will include background (ambient) and in-plume events.

4.1 Methods

The following sections describe the analytical methods that are planned for the determination of benzene, naphthalene, carbon dioxide, total particulate, and particulate bound lead. Sampled volumes will be calculated as the multiplicand of sample flowrate and sampling time. These are also described below.

4.1.1 VOCs by Method TO-15³

Benzene and naphthalene will be analyzed by Columbia Analytical Services using SIM mode GC/MS. The analysis of canister samples is accomplished with a GC/MS system. Fused silica capillary columns are used to achieve high temporal resolution of target compounds. Linear quadrupole or ion trap mass spectrometers are employed for compound detection. The heart of the system is composed of the sample inlet concentrating device that is needed to increase sample loading into a detectable range. As performed here, a 1 L aliquot is pulled from the Summa canister and analyzed.

The recommended GC/MS analytical sequence for samples during each 24-hour time period is as follows:

- Perform instrument performance check using bromofluorobenzene (BFB).
- Initiate multi-point calibration or daily calibration checks.
- Perform a laboratory method blank.
- Complete this sequence for analysis of #20 field samples.

An internal spiking mixture containing bromochloromethane, chlorobenzene-d₆, and 1,4-difluorobenzene at 10 ppmv each in humidified zero air is added to the sample or calibration standard. 500 µL of this mixture spiked into 500 mL of sample will result in a concentration of 10 ppbv. The internal standard is introduced into the trap during the collection time for all calibration, blank, and sample analyses. The volume of internal standard spiking mixture added for each analysis must be the same from run to run.

³ EPA 625/R-96-010b, January, 1999, second edition

A blank canister should be analyzed daily. The area response for each internal standard (IS) in the blank must be within ± 40 percent of the mean area response of the IS in the most recent valid calibration. The retention time for each of the internal standards must be within ± 0.33 minutes between the blank and the most recent valid calibration.

4.1.2 Semi-volatiles by Method TO-13⁴

Semivolatile sorbent sandwich samples will be prepared for analysis by solvent extraction utilizing dichloromethane and then concentrated by solvent evaporation. An Internal standard, d8-naphthalene, will be added. Samples will be analyzed in an 8270-style utilizing full-scan mode, at first, then SIM mode for additional sensitivity, if necessary. Laboratory and field blanks will be collected and prepared.

4.1.3 Carbon Dioxide by CEM

Carbon dioxide measurements will be performed using a Biosciences LI-820 NDIR-based CEM mounted on the Flyer. This unit is configured with the optional 14 cm optical bench, giving it an analytical range of 0-2,000 ppm with an accuracy specification of $< 2.5\%$ of reading.

4.1.4 Carbon Dioxide by Method 25C⁵

An aliquot of the collected Summa canister sample is injected into a sample loop equipped GC/FID. While method 25C is designed for NMOC, section 11.1.3 specifically cites the elution of sample CO₂. The method specifically converts all analytes first to CO₂ and then to CH₄ to provide uniform response across all analytes... including carbon dioxide.

4.1.5 Total PM by Gravimetric Analysis⁶

Total PM will be measured gravimetrically as the difference between final and tare masses for each filter. The procedures of Appendix O to Part 50 will be followed.

The analytical balance used to weigh filters must be suitable for weighing the type and size of filters and have a readability of $\pm 1 \mu\text{g}$. All sample filters used shall be conditioned to 20-23 °C and 30-40 % RH for a minimum of 24 h immediately before both the pre- and post-sampling weighings. Both the pre- and post-sampling weighings should be carried out on the same analytical balance, using an effective technique to neutralize static charges on the filter. The pre-sampling (tare) weighing shall be within 30 days of the

⁴ "Method 8270D: Semivolatile Organic Compounds By Gas Chromatography/Mass Spectrometry (GC/MS)"

⁵ Method 25c – "Determination Of Nonmethane Organic Compounds (NMOC) In Landfill Gases"

⁶ "Appendix L to Part 50—Reference Method for the Determination of Fine Particulate Matter as PM_{2.5} in the Atmosphere"

sampling period. The post-sampling conditioning and weighing shall be completed within 240 hours (10 days) after the end of the sample period.

4.1.6 Lead by Compendium Method IO-3.3⁷

The particulate matter collected on Teflon filters is also appropriate for the determination of lead. This method specifies analysis by energy dispersive x-ray fluorescence spectrometry (EDXRF). This method is compatible with particulate on filters, is quite sensitive for lead, and is non-destructive. By this is meant that the particulate matter and substrate survive the analysis intact; and may be archived or analyzed by other methods.

4.2 Calibration

4.2.1 VOCs by Method TO-15

Prior to the analysis of samples and blanks, but after the instrument performance check standard criteria have been met, each GC/MS system must be calibrated at five concentrations that span the monitoring range of interest in an initial calibration sequence to determine instrument sensitivity and the linearity of GC/MS response for the target compounds. For example, the range of interest may be 2 to 20 ppbv, in which case the five concentrations would be 1, 2, 5, 10 and 25 ppbv.

4.2.2 Semi-volatiles by Method TO-13

The GC/MS will be calibrated using a 5-point calibration with d8-naphthalene internal standard.

4.2.3 Carbon Dioxide by CEM

The LI-COR Biosciences LI-820 NDIR-based CEM is calibrated using a zero (nitrogen) and span gas (CO₂ in nitrogen). This will be performed in the laboratory prior to transportation to the field. Linearity checks will be performed in the lab following the calibration using 2 additional cal gases of intermediate CO₂ concentrations.

In the field, zero and span checks will be performed on a daily basis.

4.2.4 Carbon Dioxide by Method 25C

The GC is calibrated utilizing carbon dioxide in nitrogen certified calibration gases. A 4 point calibration will be performed.

⁷ EPA/625/R-96/010a, "Determination Of Metals In Ambient Particulate Matter Using X-Ray Fluorescence (Xrf) Spectroscopy"

4.2.5 Total PM by Gravimetric Analysis⁸

Calibration for determining mass of conditioned media is performed as per "Quality Assurance Guidance Document 2.12".

4.2.6 Lead by Compendium Method IO-3.3

In general, calibration determines each element's sensitivity, *i.e.*, its response in x-ray counts/sec to each $\mu\text{g}/\text{cm}^2$ of a standard and an interference coefficient for each element that causes interference with another one (See section 3.2 above). The sensitivity can be determined by a linear plot of count rate versus concentration ($\mu\text{g}/\text{cm}^2$) in which the slope is the instrument's sensitivity for that element. A more precise way, which requires fewer standards, is to fit sensitivity versus atomic number. Calibration is a complex task in the operation of an XRF system. Two major functions accomplished by calibration are the production of reference spectra which are used for fitting and the determination of the elemental sensitivities. Included in the reference spectra (referred to as "shapes") are background-subtracted peak shapes of the elements to be analyzed (as well as interfering elements) and spectral backgrounds. Pure element thin film standards are used for the element peak shapes and clean filter blanks from the same lot as routine filter samples are used for the background. The analysis of Pb in PM filter deposits is based on the assumption that the thickness of the deposit is small with respect to the characteristic Pb X-ray transmission thickness. Therefore, the concentration of Pb in a sample is determined by first calibrating the spectrometer with thin film standards to determine the sensitivity factor for Pb and then analyzing the unknown samples under identical excitation conditions as used to determine the calibration. Calibration shall be performed annually or when significant repairs or changes occur (e.g., a change in fluorescers, X-ray tubes, or detector). Calibration establishes the elemental sensitivity factors and the magnitude of interference or overlap coefficients.

Thin film standards are used for calibration because they most closely resemble the layer of particles on a filter. Thin film standards are typically deposited on Nuclepore substrates. Thin film standards are available from NIST and commercial sources.

A background spectrum generated by the filter itself must be subtracted from the X-ray spectrum prior to extracting peak areas. Background spectra must be obtained for each filter lot used for sample collection. The background shape standards which are used for background fitting are created at the time of calibration. If a new lot of filters is used, new background spectra must be obtained. A minimum of 20 clean blank filters from each filter lot are kept in a sealed container and are used exclusively for background

⁸ Quality Assurance Guidance Document 2.12. Monitoring PM_{2.5} in Ambient Air Using Designated Reference or Class I Equivalent Methods. U.S. EPA, National Exposure Research Laboratory. Research Triangle Park, NC, November 1988 or later edition. Currently available at: <http://www.epa.gov/ttn/amtic/pmqaainf.html>.

measurement and correction. The spectra acquired on individual blank filters are added together to produce a single spectrum for each of the secondary targets or fluorescers used in the analysis of lead. Individual blank filter spectra which show atypical contamination are excluded from the summed spectra. The summed spectra are fitted to the appropriate background during spectral processing. Background correction is automatically included during spectral processing of each sample.

4.2.7 Sampling Flowrate

- Summa canister sampling rate is based upon a calibrated critical orifice assembly (COA) supplied by the commercial analytical laboratory supplying the canisters. The COA will be configured as per the WAM's instructions and calibrated by the supplying laboratory.
- Semi-volatile sampling utilizes the BLDC blower. The flowrate is measured by the pressure differential measured across the installed venturi. The voltage equivalent to this pressure differential will be recorded on the HOBO external event logger. This will be calibrated in the APPCD Metrology laboratory utilizing Roots meter.
- The filter sampler utilizes an SKC Leland Legacy constant rate sample pump. The patented (U.S. Patent No. 5,892,160) internal flow sensor measures flow directly and acts as a secondary standard to constantly maintain the set flow. Set flow is achieved immediately at start-up and flow calibration is automatically maintained by built-in sensors that compensate for differences in temperature and atmospheric pressure during sampling. The patented (U.S. Patent No's. 6,227,031 and 6,363,769) built-in CalChek feature provides direct communication to a Defender primary standard calibrator for fast and easy calibration without manual adjustments. The Defender calibrator is sold separately or available in convenient Leland Legacy CalChek pump kits. Flow rate: $\pm 5\%$ of set-point after calibration to desired flow. The volume display is continually updated, based on corrected flow rate multiplied by sampling time. The display presents the pump serial number, pump software revision level, flow rate, volume, temperature, atmospheric pressure, time of day, run time, and pump status, i.e., hold and run as well as Setup information.

4.2.8 Sampling Time

Sampling time will be based upon data logged onto the HOBO U12-006 4-channel external logger. Each recorded event is time and date stamped. The HOBO maintains an internal time, which has a time accuracy of ± 1 min per month. Since all sample times are based upon differentials across sampling times on the order of several minutes, no further calibration is necessary.

5. QUALITY ASSURANCE/QUALITY CONTROL

5.1 Comparisons

As a QA check, the results obtained from integrated extractive sampling and analysis by conventional methods will be compared to the corresponding continuous sampling techniques, when available.

5.2 Quality Objectives and Criteria

The objective of this project is to characterize the emissions FOR ob/od EVENTS. The data quality objectives (DQOs) define the critical measurements (CM) needed to address the objectives of the test program, and specify tolerable levels of potential errors associated with data collection as well as the limitations of the use of the data. The different technologies used will be compared on the same basis using the same critical measurements whenever possible. However, the critical measurements used in the computation of the emission data shall also satisfy the data quality indicator goals specified by the respective sampling methods based on a Pass/Fail criterion, such as pre-sampling surrogates recoveries that are not included in the computation.

The following measurements are deemed to be critical to accomplish the project objectives:

- PM weights
- Target pollutant concentrations
- Sample volumes
- Sampling time

These measurements are needed to determine the emission factors and emission rates for the various pollutants. The time sequence of sampling events must be recorded on the same time axis as are the current CEM data streams. This is essential to determine the extent of the emissions as a function of the damper mode (closed or open) and the fuel charge consumption as a function of time.

5.3 Data Quality Indicator Goals for Critical Measurements

The data quality indicators (DQIs) are specific criteria used to quantify how well the collected data meet the DQOs. The DQI goals for the critical measurements correspond to and are consistent with the standards set forth in each respective referenced EPA Method. Accuracy and precision estimates are available where noted, and completeness goals for data collection and sampling are indicated in Table 5-1.

5.3.1 DQI Goals for the Target Pollutants

The DQI goals for the critical measurements for PM and organic sampling (listed in Table 5-1) correspond respectively to the standards set forth in each respective EPA Method.

Table 5-1. Data Quality Indicators.

Measurement Parameter	Analysis Method	Accuracy	Detection Limit	Completeness %
Benzene	GC/LRMS	15% of modified SM-4500-E	0.075 µg/m ³	90
Naphthalene	GC/LRMS	5% of Standard solution	0.1 µg/m ³	90
Naphthalene	GC/LRMS	20 %	30 ng/m ³	90
PM	Analytical Balance	15 %	1 µg	90
Lead	EDXRF	6%	0.45 µ/m ³	90
Carbon dioxide	NDIR CEM	3 % of reading		100
Carbon dioxide	GC			90
Flowrates	Venture differential pressure	99+%	144 slpm	100
	Critical orifice			100
	Internal flow sensor	± 5 % set point		100
Sampling Time	Computer clock	1' per month	2"	100

5.3.1.1 PAHs

A single TBD deuterated PAHs (see Table 6-2) is to be added to the XAD-2 trap before the sample is collected. The surrogate recoveries are measured relative to the internal standards and are a measure of the sampling train collection efficiency. All surrogate standard recoveries shall be between 25 and 130 percent. A deuterated recovery standard, TBD_i, will be added before mass analysis.

Table 5-2. PAH Surrogates, Composition & Purpose.

Spiking Solution	Analytes	Special Notes
Pre-sampling surrogate	TBD, deuterated PAH; Naphthalene std	added to sorbent pack prior to shipment to field
PAHs - Internal Standards	Naphthalene-D8	Added to the sample prior to extraction
Recovery	TBD, deuterated PAH	Added before mass analysis

5.3.2 Representativeness and Comparability

At least five samples per analyte are targeted for measurement and comparison. Results will be compared with minimally existent emission factors from the literature.

5.4 Assessing DQI Goals

In general, data quality indicator goals are based on either (1) published specifications, (2) related quantities (like drift for precision), or (3) engineering judgment based on previous experience with similar systems.

5.4.1 Precision

In order to measure precision, it is necessary to make replicate measurements of a relatively unchanging parameter. The ability to measure precision is dependent upon the type of data that is being measured. With an analytical balance or a CO analyzer, all it takes to measure precision is to measure the value of a reference standard more than once and compare the two numbers. To check precision, any pair of duplicate measurements can be entered into an equation of the form:

$$RPD = \frac{100 \times |Q - B|}{(Q + B) / 2} \tag{5-1}$$

Where:

Q = results from one run

B = results from second duplicate run

RPD = relative percent difference

If more than one pair of duplicate measurements is available, an entire population of individual precision can be generated. The best way to represent all of the replicate responses to a reference standard is with a relative standard deviation (RSD):

$$RSD = \frac{\sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}}{\sqrt{n-1} \bar{Y}} \tag{5-2}$$

This is often expressed as a percent.

When there are no reference standards, however, precision calculations are at the mercy of system stability. Furthermore, several of the measurements only generate one value per run (i.e., for 2 runs per condition, Precision = RPD). Therefore, for measurements that are compared to a reference standard, precision can be measured on a per-run basis as RPD. Overall precision for the entire test series can be expressed as RSD. For measurements that have no reference standard, precision is expressed as RSD for multiple measurements per run, and as RPD for singular measurements.

5.4.2 Accuracy

The accuracy of a measurement is expressed in terms of percent bias, or, in some cases recommended by the EPA standard methods, in terms of absolute difference. Percent bias is defined as:

$$Percent\ Bias = \frac{R - C}{C} \times 100 \tag{5-3}$$

Where: R = instrument response or reading
 C = calibration standard or audit sample value

Accuracy can take on the units of the measurement, it can be expressed as a percentage of the average measurement, or it can be expressed as a percentage of the measurement range.

5.4.3 Completeness

The ratio of the number of valid data points taken that meet DQIs goals to the total number of data points planned is defined as data completeness. All measured data are recorded electronically or on data sheets or project notebooks.



6. DATA ANALYSIS, INTERPRETATION, AND MANAGEMENT

Data produced includes digital acquisition logs recorded by the computer, data generated by the automatic titrator, notes recorded in a laboratory notebook, digital pictures of the coupons, and all the sample analysis produced by the accredited laboratory. One laboratory notebook at a time will be maintained for this project, to be used for recording data by any personnel. This or these laboratory notebooks will be archived by ARCADIS for ten years.

6.1 Data Reporting

For each run, digital acquisition data, pictures of the sampling location, raw laboratory results, and processed data will be reported. All data validation criteria will be reported along with deviations from the test setting requirements and associated comments related to these deviations.

6.2 Data Validation

Data validation is performed at the end of the project through an assessment of the Data Quality Indicators (DQIs) that are specific criteria used to quantify how well the collected data meet the Data Quality Objectives (DQOs). The measured DQI for the critical measurements will be compared to the defined DQOs set in this QAPP and that are consistent with the standards set forth in each respective referenced EPA Method.

6.3 Data Storage

Field data will be transferred from the Hobo data loggers to "data sticks" via a laptop computer with a USB port. Electronic data and pictures will be posted in the DTRL folder on the EPA network share drive upon return from the field or as it is generated or received.

7. Assessment and Oversight

7.1 Assessments and Response Actions

Assessments are an integral part of a quality system. This project is assigned a QA Category III and does not require planned technical systems and performance evaluation audits. However, should deficiencies be identified by any of the key individuals responsible, an interoffice memorandum will be prepared and submitted to the ARCADIS and EPA project participants. The memorandum will discuss the problem and corrective actions taken. A QA performance evaluation will be performed to determine if DQIs goals were met for the overall project. Any internal audits performed by the ARCADIS QA staff will be followed by a written formal report to the EPA QA Manager and WA Manager.

7.2 Reports to Management

All assessments performed by the EPA QA Representative or internally by the ARCADIS QA Officer will be formally reported to the EPA and ARCADIS WA Managers within 30 days. Findings from the audits will be reported immediately in order for any necessary corrective actions to be implemented.

The final report prepared for this project will contain a discussion of QA procedures and an evaluation of whether or not established DQI goals were met. In the event DQIs are outside of the acceptance criteria, the consequences of the failure to meet specific DQI goals will be discussed.

7.3 Corrective Actions

The ARCADIS WAL (Dr. A. Touati) is ultimately responsible for implementing corrective actions identified through QA Audits. An integral part of any QA program is well-defined procedures for correcting data quality problems. The overall goals of the QA program address the following aspects of data quality:

- Problem prevention
- Problem definition
- Problem correction

For this type of testing, data-quality problems usually require immediate, on-the-spot corrective action. The procedures outlined in this plan are intended to provide for rapid detection of data-quality problems. The experienced personnel assigned to this project will be intimately involved with the data on a daily basis. A data-quality problem will become apparent soon after it occurs. On-the-spot corrective actions will be taken

**Determination of Emission
Factors from Open Burning
and Open Detonation of
Military Ordnance**

Version 0.1

Date: January 2010

ARCADIS

when practical and are expected to be an everyday part of the QA process. The EPA WA Manager will be notified promptly of QA problems that may require extended time for corrective action. The nature of the problem and corrective steps taken will be noted in the project notebook for future reference.

The ARCADIS QA Officer and the ARCADIS WAL will conduct regular inspections of project notebooks to assure completeness. Any discrepancies requiring prompt data quality problem correction will be followed up with the WAL. Through regular discussions with the project staff, the QA Officer and WAL will ascertain the continuing suitability of analytical systems performance. Because communications between project participants are open and frequent, this system is expected to be effective and will require a minimum amount of paperwork. The ARCADIS QA Officer will make documentation of problems requiring long-term solution.

7-2

8. Checklist – Brian Gullett's

Tooele people:

- Smoke grenade – 20
- M1 – 7200 lb max
- Safety distance for 200 lb of M1
- TNT – 5400 lb max
- Burn pans – 4 plus spares
- 4 OD Shelters – 2 for ATVs, 1 for balloon, 1 for people
- Safety briefing March 9 (EPA and ISSI) and March 15 (Rood, Hashmonay)
- Fence, gates, coordinate with Rob Gribble of ISSI
- Weather warnings on-site (from whom, when?)
- Helium source?
- Local welding shop?
- Cal gas source?
 - [Air Products & Chemicals Inc](#)
 - 745 S Frontage Rd, Centerville, UT
 - (801) 298-4881 [Website](#)
 - [Airgas Intermountain](#) (National Welders/National Specialty Gases)
 - 3415 S 700 W, West Valley, UT
 - (801) 288-5000 [Website](#)

- Calibration gas delivery address?
- Refrigerator at test range for samples and/or an ice source?
- Hardware store, electronic store, walmart, batteries
 - True Value Hardware
 - 800 North Main Street, Tooele, UT
 - (435) 882-0896
 - The Home Depot #4419
 - 222 E 2400 North
 - Tooele, UT 84074
 - (435)843-7530
 - Parktek Electronics
 - 493 Country Cib Tooele, UT 84074
 - (435) 882-7664
 - Radio Shack
 - 500 E Village Blvd Stansbury Park, UT 84074
 - (435) 837-4226
 - Wal-mart Supercenter
 - 99 W 1280 N
 - Tooele, UT 84074
 - (435) 833-9039

- BatteriesPlus
 - 293 East 3300 South,
 - Salt Lake City 84115-3903
 - Mon—Thurs: 7:45-7:00, Fri : 7:45-7:00, Sat: 9:00-4:00, Sun: Closed
 - 801.461.4988
 - Fedex procedure, shipping address? Pickup procedures?

 - FEDEX NATIONAL LTL
 - 750 N 5600 W, Salt Lake City, UT

 - (801) 736-8100 [Website](#)
 - Hospital name, location, capabilities (burn, cardiac, etc.)?
 - Base emergency procedures, first aid kits?
 - Daily food source (other than the cafeteria)? Can we bring food on-site?
 - Food storage capabilities at the test range (refrigerator?)
 - Internet access at test range?
 - Ability of visitors to attend?
 - Is there a balance/scale at the test range? What sensitivity? When last calibrated?
 - Hardwire or wireless internet available at Test Range?
 - Desk area available at test range for computer work?
 - Lavatory facilities for 6 + Rood/Hashmonay/Kim crew + visitors, Male/Female
 - Recommended clothing – ask Roger Hale
- ISSI:
- Helium cylinders – 20 (a pallet is 16). 3 ½ cyl per balloon, ½ cyl /day leakage. From where? Delivery procedures?
 - ATV – 3
 - Balloon cart: construct
 - Balloon overnight, rain proof and tie down
 - Radios
 - Seal vacuum for helium transfer
 - ATV instructional classes: 2 ISSI persons, BKG, JA, Donnie, Chris ?
 - Range finder, binoculars
 - Coordinate equipment list with EPA
 - Fence, gate openings. Coordinate with Roger Hale
 - Remote control of tether spools, balloon release mechansim
- EPA
- Burn Hut test plan – JA
 - NC trial test plan –TBD, BKG
 - Field safety protocol – BKG
 - Clothing – JA to ask Roger
 - Maps – BKG (have)
 - Flashlights –
 - Equipment list - JA
 - Safety clothing – vests, JA

- EPA Field safety training – all (Brian, see your email from Marshall).
- Holiday Inn Suite – BKG
 - 1531 NORTH MAIN, TOOELE, UT 84074
 - \$106.00 - \$146.00 USD Average Nightly Rate Range
 - Hotel Reservations: 1 800 315 2621
 - Indoor Pool, Complimentary Breakfast, On-site Guest Self-Laundry Facilities (washer/dryer), Coffee Maker, Health/Fitness Center On-Site
- Mitchell Lindsay review – BKG (ARCADIS subcontract?)
- Coordinate equipment with ISSI - Brian
- Flyer safety boxes, 3? - JA or CP orders
- Sample boxes – JA (Dennis working on wrapping procedure)
- Video + camera – BKG (has asked Scott Moore)
- Computers – BKG (has a preliminary quote)
- Memory sticks - JA
- Scale, balance? - JA
- Flyer spare list – JA and CP
- Step by step test plans – BKG and JA (see below)
- Daily Testing checklist and estimated schedule - JA and CP, also Rob
- Flyer operating procedures – JA and CP
- Small battery for CO2-only tests? CP w/ JA
- Generators?
- Personnel decision – who goes? ISSI will have two people there.
- Range finder – BKG
- New GPS (altitude, stored coordinates/height vs. time) – CP
- Summa contract/mechanism – CAS, David
- "trial balloons" buy - DT
- Pump computer program, SKC - \$150 CP
- 3 Tripods for camera and video camera and flyer (have 2 need 1 for video camera) – DT
- CAS valve/orifice vs. 1, 2, 4 10 minutes. Have them deliver two Summas to us ASAP for our tests, including a TO14 fill.

Test Plan (incorporate into QA plan)

- Week 0.
 - Safety briefing
 - ATV certification
 - ATV/He sled(s)
 - ATV test drive on test range, without then with balloon
 - smoke grenade, small balloon, maneuver practice (dry run)
 - Test run: smoke grenade, single M1 burn, record CO2 only, practice following the plume. CO2 concentration x time allows us to adjust future test protocols.
- Repeat test run with single OD.
- more

Appendix B: Test Plan for Field Campaign at Tooele Army Depot

Determination of Emission Factors from Open Burning and Open Detonation of Military Ordnance

Test Plan

Proof of Concept Field Campaign: Tooele Army Depot

Prepared by: Mark J. Rood, Wangki Yuen, David Johnsen, Srirupa

Ganguly, and Sotiria Koloutsou-Vakakis

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Ram Hashmonay

ENVIRON, RTP North Carolina

March, 2010

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Select portions of this report were obtained directly from USEPA's QAPP

Distribution List

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Wangki Yuen	(UI)
Robert Wright	(EPA)
Brian Gullett	(EPA)
Ryan Williams	(U.S. Army Defense Ammunition Center)

1. Project Description and Objectives

This Test Plan provides guidance to personnel conducting emission testing under Strategic Environmental Research and Development Program (SERDP) Project WP-1672 "Determination of Emission Factors from Open Burning and Open Detonation of Military Ordnance."

This report is designed to develop and apply methods for sampling Open Burning/Open Detonation (OB/OD) of military ordnance in the field to characterize gaseous and particulate matter (PM) emissions. The project's objective is to provide information demonstrating proof of concept for new measurements systems for characterizing OB/OD air emissions. During this work we will use an integrated system consisting of the following novel measurement technologies:

- An aerial, balloon-borne instrument package for measuring particulate matter (PM) and gasses developed by the USEPA ("The Flyer").
- A PM₁₀ measurement system consisting of Micro-Pulse Light and detection and ranging (MPL), open path-laser transmissometers (OP-LT), and Tapered Element Oscillating Microbalances (TEOMs) (i.e., MLT system).
- An optical remote sensing (ORS) gaseous measurement system consisting of active and passive open-path Fourier Transform Infrared (OP-FTIR) spectrometers and Ultraviolet Differential Absorption Spectrometers (UV-DOAS).

This document covers in detail the background, objectives, and technical approach aspects of data collection and analysis. This document will also describe the integration of the measurement systems in the field and the integration of analysis results. Where appropriate this Test Plan will refer to the US Environmental Protection Agency's Quality Assurance Project Plan (USEPA QAPP) that covers method development and data collection and analysis from the Flyer¹.

1.1 Background

U.S. Department of Defense (DOD) installations, especially demilitarization facilities and Army Ammunition Plants (AAPs), have used Open Burning/Open Detonation (OB/OD) for a long time as a safe and economic means to dispose of propellants, explosives, and munitions. DOD installations are required to comply with the Resource Conservation and Recovery Act (RCRA) to operate OB/OD facilities. RCRA permits provide

¹ *Determination of Emission Factors from Open Burning and Open Detonation of Military Ordnance Quality Assurance Project Plan, Category IV / Proof of Concept. Draft - Revision 0.1, U.S. Environmental Protection Agency Air Pollution Prevention and Control Division, January 2010*

annual limits on the amount of energetic materials that can be disposed of at OB/OD facilities. The permit limitations are based on human health risk assessments that include risk estimates from airborne exposure to pollutants generated from OB/OD. These assessments use emission factors developed mostly from a limited number of tests on small scale OB/OD chambers, known as a "Bang Box", and large scale open range detonation and burn tests. There is a continued need, however, to further develop methods of sampling these events to add to, and support, current data.

1.2 Objectives

This project's objectives are to develop and implement new techniques to measure both PM and gaseous emissions that can be used to quantify emission factors from simulated OB/OD operations at Tooele Army Depot, Utah. The combined *in situ* open path and ORS measurement systems will provide measurements of PM₁₀, measurements of lead, chemical speciation of gases, calculation of emission mass fluxes over time, and the calculation of emission factors. The USEPA QAPP provides details about method development for the Flyer and the following sub-sections provide more information on method development for the MLT system and the ORS gas measurement system.

1.2.1 Method Development for the MLT System

The MLT system integrates MPL and OP-LT technology with a real-time in-situ point extractive TEOM (Automated Equivalent Method: EQPM-1090-079, Federal Register: Vol. 55, page 43406, 10/29/90) technique, anemometers, data acquisition, and remote communication (Figure 1-1). The instruments will be located downwind of the source of emissions with measurements occurring within the plumes (Figure 1-2). The MPL will measure across a plane that is located downwind from the source. The location of the measurement plane will depend on PM concentrations and the ability of the PM plume to attenuate visible light and disperse during transport. The MPL will operate on a positioner and will be located in an air conditioned trailer that is about 500 m away from the ground-level centerline of the plume. The MPL will be used to determine the light scattering and extinction distributions of the plumes' entire cross-sections. The anemometers will be located with the field equipment to determine wind speed along the cross-sectional measurements of the MPL. The OP-LT and TEOM will also operate parallel to the measurements by the MPL, but may be operated closer to the sources depending on the properties of the plume and the ability of the instruments to detect the plume. The OP-LT and TEOM will determine the aerosol's real time path integrated extinction value and mass concentrations of PM₁₀. These values are then used to determine the aerosol's mass-based light extinction efficiencies. Light extinction efficiency is a normalized value that is much less variable than the absolute value of either of the individual values. A Global Positioning System (GPS) will determine the altitude, longitude, and latitude of the measurement devices with confirmation of distances between the measurement devices with range finder measurements.

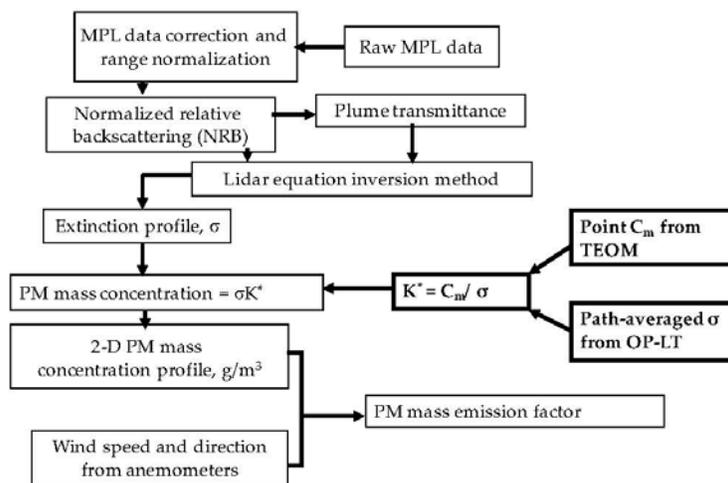


Figure 1-1 Description of MLT system to determine PM₁₀ mass emission factors.

The analysis steps required to determine PM mass emission factors is described graphically in Figure 1-1. The emission factor (EF) from open burning or detonation of energetic materials will be calculated using the following equation.

$$EF = \frac{\sum_{t=0}^T (\sum C(A,t)\Delta A) u(z) \cos \theta \Delta t}{M_{energetic}}$$

where, EF = emission factor (g PM₁₀ / kg energetic material)

T = total time that the plume travels across the MLT scan plane (sec)

C(A,t) = mass concentration of a point in vertical plane (A) at a time (t), measured by MLT system (mg/m³)

u(z) = wind speed as a function of height (z), measured by two anemometers that are mounted at the two different heights (m/s). The power law will be used to fit wind speed versus height in obtaining wind speed at other heights.

Θ = wind direction relative to the perpendicular of the scan plane of the MLT system (degree)

M_{energetic} = mass of energetic material burned or detonated (kg)

1.2.2 Method Development for using ORS to measure OB/OD gas emissions

We will determine the feasibility of new gas emission characterization technology from full scale OB/OD using an integrated open path *in situ* measurement techniques and ORS system measurements downwind of OB/OD sources. The open path system will include active and passive OP-FTIR spectrometers and UV-DOAS. These will be complemented with an OP-LT and MPL provided by the UI.

The plume gases will be identified and quantified from the OP-FTIR and UV-DOAS spectral data. MPL measurements extend the range and spatial information that is provided by the OP-FTIR, UV-DOAS and OP-LT. This integration of the spectroscopic instruments with MPL and point monitors will improve the quantitative interpretation of the gases and PM in the OB/OD plumes. In addition, an EPA "Flyer" type measurement system will be located on the ground near the TEOM location. **Figure 1-2** shows a conceptual drawing of the ORS measurement system setup.

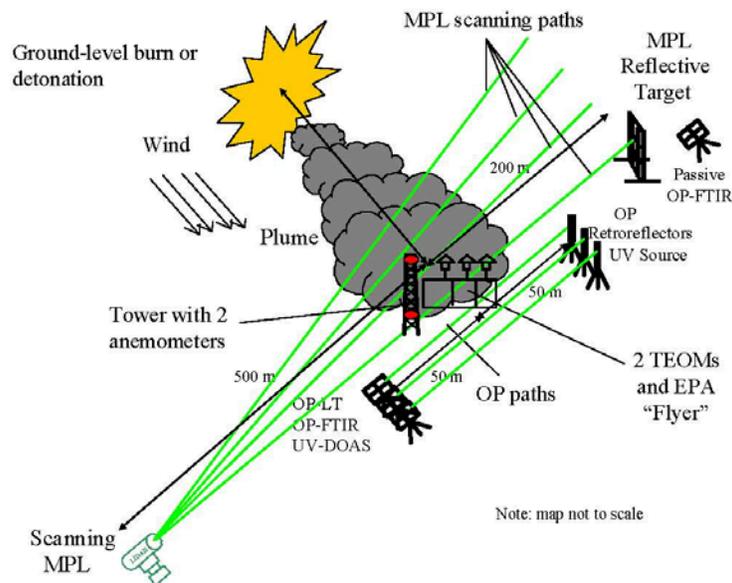


Figure 1-2 General instrument layout for the field study

1.3 Project Schedule

The USEPA QAPP provides details about project schedule information for the Flyer. Some of the information below describing the site and field activities is repeated from the same sections found in the USEPA QAPP.

1.3.1 In-House Development of the MLT System

Two TEOMs were acquired from the Department of Agricultural and Biological Engineering at UI. Both TEOMs will operate with an inlet that allows particles with aerodynamic diameter $< 10 \mu\text{m}$ into the device. The custom OP-LT device was built in the Air Quality Research Laboratory at UI and has been field tested. The TEOMs, anemometers, data acquisition system, and remote communication have also been tested. The primary purpose of the testing was to evaluate and modify the system to allow for simultaneous operation of the instrumentation with data acquisition remote communication. The MPL has been field

tested by UI. All equipment was working properly. Some modification to the data acquisition system was needed to account for a USB interface from the OP-LT.

1.3.2 Field Measurements

The MLT PM_{10} measurement system will be used to continuously measure PM_{10} concentration, light attenuation from PM in plumes generated from the OB/OD of military ordnance. The ORS gas measurement system will continuously measure and later identify gasses found in the OB/OD plumes. The field measurements will be made at the Tooele Army Depot, Tooele County, Utah during 15-26 March 2010. A map of the area where measurements will occur is provided in Figure 1-3.

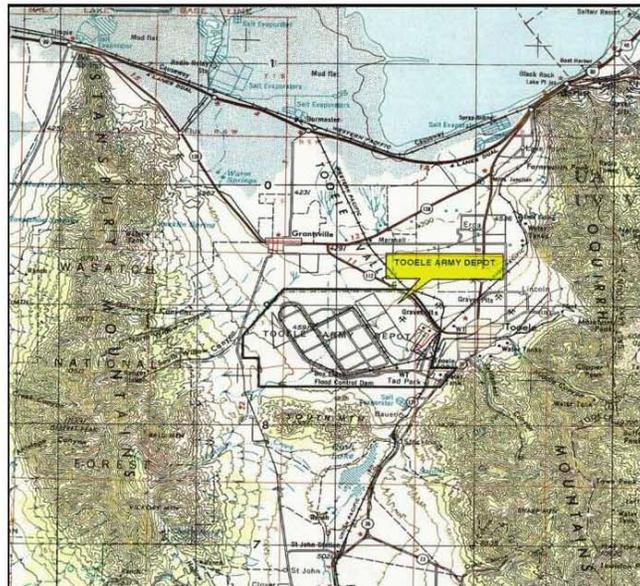


Figure 1-3 Map Locating Tooele Army Depot

Figure 1-4 provides a close-up map of the Test Range which consists of an indoor facility, bunkers, a detonation test range, and a concrete pad for OB/OD tests. The elevation at the Tooele Test Range is ~5,500 feet above sea level. The Test Range consists of a concrete pad (~25x25 meter, inside the small

red and green circles) for the OB tests and a gravel/sand field (~100×50 meter) for the OD tests (small gray rectangle). The OB and the OD tests are video monitored and recorded from the indoor facility/bunker (#1376) on Figure 1-4.

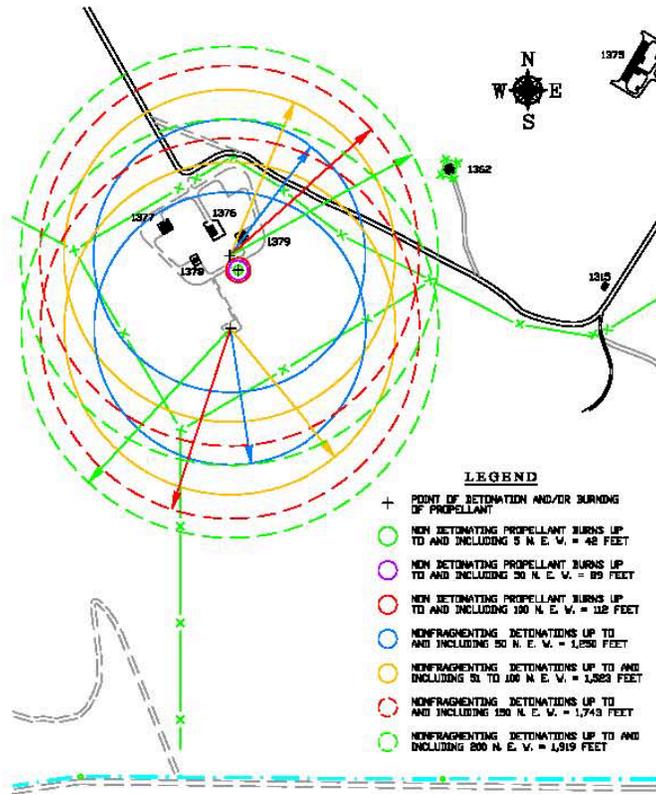


Figure 1-4 Map of Tooele Test Facility

Meteorological data such as wind speed, wind direction, and temperature will be collected from the Salt Lake City National Weather Service, www.noaa.gov, and www.accuweather.com, which gives an hourly forecast. In addition, the Army Depot has two local weather stations that measure wind speed and wind direction at ground level (Figure 1-5). The wind direction is mostly stable in the mornings and in the afternoons while during midday the winds are unstable (i.e., fast changes in the wind direction). The predominant wind directions are south-southwesterly during the morning and then north-northwesterly during the afternoons based on meteorological measurements at Tooele's two meteorological towers during March 2007 and March 2009. During the month of March the temperature is between 20 to 60 °F (-6 to 16°C). The Army Depot local wind data will be used to locate the MLT system in addition to personnel safety. The maximum allowed wind speed for performing the detonations and burns are 15 MPH (6.7 m/s) with gusts up to 25 MPH (11 m/s). In addition, the minimum visibilities for detonations are 1 mile with not less than 2,000 ft of ceiling (cloud cover) for detonations. There are also environmental limitations to how much energetic can be ignited depending on wind direction (winds are not to be between the north-northwest and north-northeast for OB/OD above 200 lb).

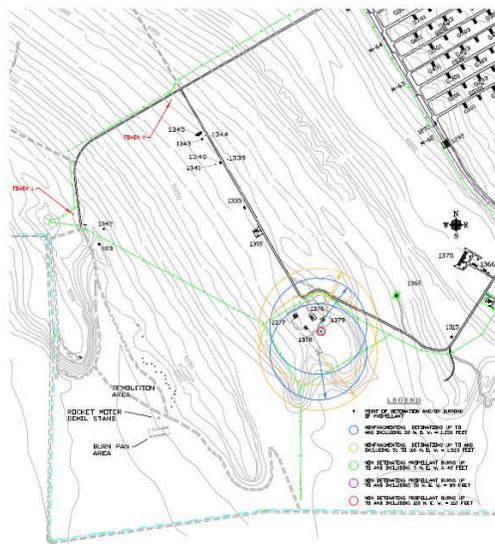


Figure 1-5 Location of Meteorological Towers at Tooele Army Depot

The proposed test matrix and schedule in this program are subject to changes in time and scope due to budget constraints or facility approval. Table 1-1 details the proposed schedule for this project.

Table 1-1. Test Schedule

Task	Start Date	Planned Completion
Test Plan	December 31, 2009	March 1, 2010
Construction of OP-LT	January 15, 2010	February 20, 2010
Integration and testing of equipment with data acquisition system and remote communication	December 1, 2010	March 7, 2010
Tooele sampling campaign	March 15, 2010 (site preparation and sampling)	March 26, 2010
Data analysis and reporting	March 29, 2010	~ June 1, 2010

2. Project Organization

The roles and responsibilities of the project personnel are discussed in the following paragraphs. In addition, contact information is also provided. More detailed information about project responsibilities related to the Flyer portion of this work can be found in the USEPA QAPP.

ERDC-CERL Project Manager, Dr. Byung Kim: Dr. Kim will be responsible for the overall execution of this project providing technical guidance to all team members. He will review their work and serve as the coordinator between the team and SERDP Office

Phone: 217-373-3481

E-mail: byung.i.kim@usace.army.mil

ERDC-CERL Co-Project Manager, Michael R. Kemme: Mr. Kemme will be responsible for coordination with DOD, Army Agencies, USADAC, the SERDP Office, assisting with data capture in the field, assisting with data analysis, and documenting project results.

Phone: 217-373-4554

E-mail: michael.r.kemme@usace.army.mil

USEPA WA Manager, Dr. Brian Gullett: Dr. Gullett has overall project responsibility. He will direct the Flyer project's technical aspects and will be responsible for maintaining project budgets. Dr. Gullett will coordinate with EPA Quality Assurance (QA), EPA management, and with the ARCADIS WA Leader (WAL). He will

schedule meetings with the ARCADIS WA Leader (WAL) to discuss issues related to the work assignment and the necessary corrective actions to be taken.

Phone: 919-541-1534

E-mail: gullett.brian@epa.gov

UI Project Manager, Mark J. Rood, Ph.D.: Mark J. Rood has overall project responsibility for the MLT PM₁₀ measurement work. He will direct the project's technical aspects and will be responsible for the maintaining the project's budget. Dr. Rood will coordinate with Byung J. Kim and Michael R. Kemme of ERDC-CERL, Ram Hashmonay of Environ, and Brian Gullett of USEPA.

Phone: 217-390-2237

E-mail: mrood@illinois.edu

ENVIRON Dr. Ram Hashmonay has overall project responsibility for the gas emission measurement work. He will direct the project's technical aspects and will be responsible for maintaining project budgets. Dr. Hashmonay will coordinate with Byung J. Kim and Michael R. Kemme of ERDC-CERL, Mark Rood of UI, and Brian Gullett of USEPA.

Phone: 919-616-6336

E-mail: rhashmonay@environcorp.com

UI Ph.D. Graduate Student, Wangki Yuen: Wangki Yuen is responsible for preparing the experimental apparatus, implementing the field campaign, and then analyzing the results from the MPL, OP-LT, TEOMs, and the anemometer measurements.

Phone: 734-218-2119

E-mail: yuen4@illinois.edu

UI Ph.D. Graduate Student, David Johnsen: David Johnsen is responsible for preparing the data acquisition system, remote communications between the instrumentation and data acquisition systems, supporting Wangki Yuen and Rami Hashmonay in the field.

Phone: 630-215-9172

E-mail: johnsen2@illinois.edu

3. Experimental Approach

Detailed information about the experimental approach employed for the Flyer is presented in the USEPA QAPP. Some information from the USEPA QAPP is presented below along with details about the MLT PM₁₀ sampling system, the ORS gas sampling system, and analysis and integration of data from all sampling and measurement technologies.

Before the start of each day's sampling of OB or OD emissions the instruments shown in Figure 1-2 will be placed directly downwind of the OB or OD site. The downwind direction will be selected by considering the forecast wind directions for the day and the wind direction monitored at the site. If a wind direction shift is forecast, the instruments will be placed in the direction where the wind will be blowing for the majority of the day. The goal is to avoid having to move the instruments during the day if possible. During the first week of the field campaign (i.e., 9 March – 13 March 2010), researchers will attempt to correlate forecast wind speeds and directions with actual test site conditions. The first week of the field campaign will also provide an indication of OB/OD plume lofting under different meteorological conditions. Several trial burns and detonations will occur and the plume loft will be viewed relative to the position of a test balloon.

The downwind distance will be chosen to maximize the pollutant concentration seen by the measurement systems without overwhelming any of the instruments with too large of a PM load. There has been some preliminary study of downwind concentrations of pollutants that will help in deciding these distances and the purpose of the first week of the field campaign is to help narrow down the distances further. Initial measurements by the MLT PM₁₀ and the ORS gas measurement systems will immediately show if the plume concentrations are in an acceptable range. Before each OB and OD event begins, the wind speed and direction will be monitored and the event will be held until acceptable conditions are achieved and there is a reasonable likelihood that the acceptable conditions will persist during the entire OB or OD event.

All decisions regarding the safe and acceptable conduct of the OB and OD operations will be made by the Tooele Army Depot Test Director. Other field decisions regarding plume measurements will be run through a single individual who will be in constant contact with the Test Director. The plume measurement decision maker will have the authority to unilaterally make decisions for the entire plume measurement team in the event a quick decision is required. Decisions that don't need to be made quickly will be reached through consensus of test team members.

Some potential field problems have been raised and are discussed below. These include misfires; changing meteorological conditions that affect plume movement, dispersal and lofting; rain; and equipment breakdowns. In the case of a misfire during an OB or OD event, the general rule of thumb will be to immediately initiate the next scheduled burn or detonation in the series and to continue with measurements of the plume. If several misfires occur, the OB or OD series may be stopped if it is likely that there is insufficient mass of pollutants to make meaningful measurements. The decision about varying

meteorological conditions causing changes in plume direction or lofting will be based on the ability of the EPA Flyer, and the combined MLT PM₁₀ and ORS gas measurement systems to continue measuring the plume. If none of the systems are sampling and making measurements, the OB or OD event will be halted. On the other hand if one of the systems is still adequately making measurements and sampling, the OB or OD event will continue. If rain occurs before an OB or OD event the event will be delayed until the rain stops. If rain begins during an OB or OD event, the event will in most cases continue. Local weather radar will be used to help determine if rain is likely to occur during OB and OD events. In most cases an equipment breakdown problem will not result in an OB or OD event being stopped. Team members will need to reach consensus about delaying subsequent OB or OD events after equipment problems. For the ORS gas measurement system, the OP-FTIR measurement is the most critical and testing might be held to fix problems with the OP-FTIR. For the MLT PM₁₀ measurement system the following highest to lowest priorities exist when making decisions about holding measurements until a repair can be made:

- Data acquisition system,
- Range-resolved aerosol backscatter and extinction coefficients (MPL),
- Direction of MPL (Positioner),
- Wind speed and wind direction (Anemometer),
- PM10 mass concentration (TEOM), and
- Path integrated aerosol light attenuation (OP-LT).

3.1 MLT-PM and ORS-Gas Measurement Sampling Approaches

The MLT system, Figure 1-2, combines open path and in-situ extractive techniques to integrate the optical and mass concentration based properties of the aerosol generated by OB/OD of ordnance described in Table 3-1 to determine PM₁₀ emission factors for those operations. Estimated PM₁₀ emission factors for OB and OD are presented in Table 3-2. Detonations include the use 1.25 lbs of C-4 to initiate detonations of both the 100 lbs and 200 lbs TNT detonation events. Table 3-1 includes the composition of C-4. Power will be provided by two generators.

Table 3-1. Composition of OB and OD Ordnance

Material	Mass %	Composition	
M1	84	Nitrocellulose	$C_6H_7(NO_2)_3O_5$
	9	2,4-dinitrotoluen (DNT)	$C_6H_3(CH_3)(NO_2)_2$
	5	Dibutyl phthalate (plasticizer)	$C_{16}H_{22}O_4$
	1	Diphenylamine	$(C_6H_5)_2NH$
	1	Lead carbonate	$PbCO_3$
TNT	100	Trinitrotoluene	$C_7H_5N_3O_6$
C-4	5.31	Diocetyl Sebacate	
	0.13	Lubrizol	
	1.31	Mineral Oil	
	2.25	Polyisobutylene	
	91	RDX	

Table 3-2. Emission Factors²

Analyte	Units	TNT, OD	M1 propellant, OB
PM ₁₀	lb/lb NEW	7.2	0.0069

lb/lb NEW pound per pound net explosive weight

Sampling will occur after each of single or multiple (in series) OB/OD tests. Each series of tests (whether single or multiple) is defined as an event. The number of events per sample will be determined by test conditions during the field campaign.

For each of the OB and OD scenarios, a five day sampling campaign with morning and afternoon events, is planned as the maximum number of sampling periods. For the first week, five days of morning and afternoon tests will result in nine OB events (the first day will include set-up, the initial background sampling and one event sampling). Similarly, the second week will result in five days of morning and afternoon OD events for a total of 10 events with set-up occurring during the previous weekend and early morning. Background sampling will occur before and after each OB or OD event. The maximum number of tests that a single analyte will be sampled is nine for OB and 10 for OD, plus background and blank samples. The minimum desirable tests for a single analyte are the same as the maximum values.

² AP-42 Draft Chapter 16 "Emission Factors for Demilitarization Processes: Open Burning and Open Air Detonation"

The combination of OP-FTIR and UV-DOAS sensors were chosen to determine the path-integrated concentrations (PICs) of the gaseous components of the plume. The OP-FTIR sensor is capable of detecting and measuring any gas-phase compound that is infrared active, which includes the majority of gaseous components. Since some important species have high detection limits due to interference by water vapor or CO₂, we will include UV-DOAS since it has very low detection limits for measuring benzene, nitric oxide, and sulfur dioxide. The potentially large concentration of PM in the plume will increase the detection limits for gasses but will not affect the ability to measure gasses that are above detection limits. Another FTIR application that will be employed and tested is the solar occultation flux method. For assessment from the ground of the entire vertical OB/OD gas plume, a passive FTIR will use radiation from the sun as an infrared source by manually aiming the FTIR telescope through the plume directly at the sun. The passive FTIR will be placed on the northern side and downwind of the OB/OD events outside of the safety circles. The field tests will determine the tolerances of this method to cloud cover and alignment with the sun.

3.2 Analytes and Process Measurements

The following list describes the critical measurements:

- Range-resolved aerosol backscatter and extinction coefficient
- PM₁₀ mass concentration
- Path integrated aerosol light attenuation
- Wind speed and wind direction
- PIC for each gas detectable by OP-FTIR and UV-DOAS

Table 3-3 presents the planned sampling and analysis methods.

Table 3-3. Sampling and Analysis Methods

Target Measurement	Sampling Method	Sampling Rate	Analysis
Range-resolved aerosol backscatter and extinction coefficient	MPL mounted on a positioner	1 vertical scan/10 sec	Range resolved aerosol particle backscatter of light at 527 nm
PM ₁₀ mass concentration	TEOM ^a	0.5 Hz	Vibration of a crystal and gas volumetric sampling rate
Path integrated aerosol light attenuation	OP-LT	1 Hz	Path integrated attenuation of light at 532 nm
PIC for gasses	OP-FTIR	2 – 5 sec	Absorption of different wavelengths of IR radiation
PIC for gasses	UV-DOAS	2 sec	Absorption of different wavelengths of UV radiation
Wind speed and wind direction	Two anemometers	1 Hz	Frequency and direction of two propellers mounted on anemometers

^a = The TEOM can sample typical ambient aerosol mass concentrations (10s $\mu\text{g}/\text{m}^3$) up to $5 \text{ g}/\text{m}^3$, Resolution = $0.1 \mu\text{g}/\text{m}^3$, precision = $\pm 1.5 \mu\text{g}/\text{m}^3$ (1-hour average), $\pm 0.5 \mu\text{g}/\text{m}^3$ (24-hour average), minimum detectable limit = 10 ng, $0.06 \mu\text{g}/\text{m}^3$ (1-hour average), accuracy for mass measurement = $\pm 0.75\%$

The OP-FTIR and UV-DOAS will determine a PIC for each detectable gas. The OP-FTIR and UV-DOAS will be used to target at least 14 gas-phase species, carbon dioxide, carbon monoxide, ammonia, acetylene, ethylene, propylene, formic acid, formaldehyde, acetaldehyde, hydrogen cyanide, nitrogen dioxide, benzene, naphthalene, and alkanes.

Results from UI/Environ measurements and USEPA measurements will be integrated and compared in the following ways:

The first set of comparisons will occur by co-locating one of USEPA's CO₂ concentration measurement devices on the ground with the TEOM and OP-LT measurements. Such approach will allow UI/Environ to calculate mass emission factors based on the carbon balance used by USEPA with concentrations measured by the MLT measurement system and ORS gas measurement system. These carbon mass balance emission factor results will then be compared to the emission factor results determined by the method described in Figure 1-1. that determines mass fluxes using PM₁₀ and gas concentrations, light extinction values, cross-sectional area of the plume, and wind vectors.

The second set of comparisons will be completed by using the gas flux calculations based on the CO₂ path-averaged concentrations along the OP-FTIR path and along the solar occultation path. PM distribution and relative concentration of the total plume cross sectional area concentration along the OP-FTIR paths will be evaluated for the MPL cross sectional areas. This ratio of PM path mass concentration to plane integrated mass concentration (PIMC) will be used for calculating the CO₂ PIMC need for the flux. The product of the CO₂ PIMC and wind speed normal to the cross sectional plane is the definition of the flux. Multiplying the average flux for the event by the duration of the event will give us the total CO₂ mass emitted per event. Incorporating stoichiometry, and assuming that all carbon in the detonated or burned sample is converted to CO₂, this measured carbon mass should be roughly the mass of carbon detonated or burnt in the event. Discrepancies in these mass values could originate from two sources: 1. There is incomplete combustion and a significant amount of the carbon converts to CO, elemental carbon (EC) PM and organic carbon (OC) PM; 2. There is partial plume capture by the MPL/FTIR approach; and 3. There are errors in the measurements. For the first case, we can assess with CO measurement from the active and passive FTIR measurements and apportion the PM between OC/EC and the mineral dust using the OP-FTIR and OP-LT data (see back blast artillery study, Varma et al., 2007). If after such assessment, we still observe a consistent negative bias (i.e., this method cannot account for all mass detonated or burnt) it is probably due to incomplete plume capture. In this case, we may still be able to correct for the incomplete plume capture for this data set but we would need to look at ways to improve our measurement configurations for future studies. A large positive bias would indicate a problem in the measurements or data analysis that would need to be investigated.

The third set of comparisons will be to co-locate a second set of Flyer type measurements on the ground with the MLT PM₁₀ measurement and ORS gaseous measurement planes. The co-located Flyer will include PM₁₀ measurements and gaseous measurements. Flyer concentration measurements will then be compared and integrated with the MLT PM₁₀ and ORS gas 2-D concentration profiles to compare not only concentration values but also mass emission factors for PM₁₀, and gases. Timing and co-locating the measurements and appropriate meteorological conditions are very important to achieve representative co-located measurements.

The fourth set of comparisons will evaluate results from Draft Chapter 16 AP-42 emission factors and results obtained from this field campaign.

3.3 Test Specific Sampling Procedures

3.3.1 Open Burning

The MLT system will be positioned downwind of the burn site based on anticipated wind speed, wind direction, and plume dispersion. The MPL will scan vertically to remotely measure the cross-section of the

plumes. The OP-LT will operate parallel with the MPL with the TEOMs along the side of the OP-LT. Information from the MPL is extended by locating the MPL on a positioner and by using reflective targets that are located over the measurement domain of the MPL. The positioner allows the MPL to scan along the plume's entire cross-section. The reflective targets placed on the opposite side of the plume from the MPL extend the range of the MPL's measurement capability for plumes that are too opaque for typical applications. Reflecting the MPL's light beam from the target back to the MPL's detector generates light transmission/extinction data that: (1) provide a reliable inversion of the MPL equation; and (2) extend the spatial information about the scattering and extinction distributions to a much longer range (> 10 km) (Du et al., 2007). Aerosol mass concentration from TEOMs and path integrated light attenuation from OP-LT will be used to determine the mass based extinction efficiencies of the aerosol in the plume. The mass based extinction efficiency is equal to the measured light extinction value determined by the OP-LT divided by the measured mass concentration of the particles determined by the TEOM. The extinction values determined by the MPL are then divided by the mass based extinction values to determine the mass concentration profiles of particles along the cross-sections of the plume. The product of the wind vectors perpendicular to the measurement plane of the MPL and the resulting mass concentration profiles determine the fluxes of PM_{10} across the plume. The product of the mass fluxes of the PM_{10} , cross-sectional area of the plume determined by the MPL, and duration of the plume result in the mass of PM_{10} emitted for a particular event.

Optimal locations for plume collection will be determined in the field based on the properties of the plume, meteorological conditions, and the ability of the sampling devices to detect the plumes. Elevated plumes are not an issue for the MPL because it scans in the vertical direction. Elevated plumes for the TEOM and OP-LT are an issue if the plume rises above the scissors lift where the TEOM will be located for elevated plumes. The real-time, point-based, in-situ (i.e., TEOM) and OP-LT measurements are expected to be in the plume a majority of the time during the two week field campaign. However, these measurements will not be used when the samplers are not located in the plume to determine the normalized mass extinction efficiency values of the plume. It is anticipated that personnel will always be outside of the safety range during ignition and burning. Data will be acquired on a real-time basis to allow for re-ignition of ordinances as quickly as Tooele can provide as long as the wind direction does not change.

Wind direction, wind speed, atmospheric stability, and possibly precipitation will affect the number of tests. There are two sample types (TNT, propellant) with 10 tests for the TNT and 9 tests for the propellant. The planned 19 continuous individual tests could be broken down into a larger number of smaller tests if field conditions warrant such decision (changing wind direction and wind speed). UI and ENVIRON will most likely have to move their equipment if the winds change as observed with the meteorological data from March 2007 and March 2009. Meteorological data from March 2007 and March 2009 indicate that north-northwesterly winds often occur during the morning and south-southwesterly winds often occur in the afternoon. A minimum of two hours will be needed to move the equipment if the winds change in direction

by 180°, depending on field conditions. All measurements made by the MLT PM₁₀ and ORS gaseous measurement systems are real-time. Hence UI/ENVIRON will know when their samplers are outside of the plume as their detectors' signals approach their background values.

The MPL has been field tested by UI. The TEOM has been field tested by another group at UI. The OP-LT and anemometers have been laboratory tested. The data acquisition and communication system has been laboratory tested. Table 3-4 presents a test plan for the open burning tests. Figure 3-1 illustrates the open burn site with its concrete pad. Figure 3-2 presents an open burn pan. These pans are re-usable and constructed of sheet steel.

Table 3-4. Test Plan for Open Burning Sampling

Date	M1 burn	MPL	OP-LT	TEOM	OP-FTIR	UV-DOAS	Anemometer
3/15/2010	4*200 lb	Field set-up					
		X	X	X	X	X	X
3/16/2010	4*200 lb	X	X	X	X	X	X
	4*200 lb	X	X	X	X	X	X
3/17/2010	4*200 lb	X	X	X	X	X	X
	4*200 lb	X	X	X	X	X	X
3/18/2010	4*200 lb	X	X	X	X	X	X
	4*200 lb	X	X	X	X	X	X
3/19/2010	4*200 lb	X	X	X	X	X	X
	4*200 lb	X	X	X	X	X	X
3/20/2010	Spare						

Total of 7,200 lbs of M1 is needed for this sampling protocol.

X = in-situ extractive and remote sampling will occur.



Figure 3-1 Open Burning Site



Figure 3-2 Open Burning Pan (TNT Flakes Shown)

3.3.2 Open Detonation

The MLT PM₁₀ and ORS gaseous measurement systems will be pre-positioned downwind of the detonation site. The downwind direction of the plume and the location of the instruments will be determined by the release of small balloons and smoke grenades. The OP-LT, TEOMs, OP-FTIRs, and UV-DOAS may be located inside the safety stand-off distance, each behind protective bunkers. All personnel will be outside of the stand-off distance and behind a protective bunker.

Before plume sampling from the first OD events begins, a smaller (e.g., 50 lbs) TNT detonation will be initiated to test the equipment's sensitivity to a shock wave. After the test all equipment will be checked to make sure it is still working properly and still aligned correctly. Continuous measurement results will be examined to see if there are any immediate or transient changes in measurement from the shock wave.

On each morning or afternoon of sampling, up to three detonations in series with a charge of 100 - 200 lb each of TNT will occur, for a total of 1,200 lbs per day, maximum. The detonations will be initiated with 1.25 lbs of C-4. Each detonation will have about 5-15 seconds between initiations to maximize the plume concentration while minimizing the safety standoff distance (through minimizing the charge size).

Multiple morning and afternoon sampling events consisting of multiple detonations may be used to create a single, composite sample for the USEPA Flyer. This single sample will be created by reusing the same sorbent media during multiple events. The MLT PM₁₀ and ORS gas measurement systems will operate continuously during each of the events being composited and may be able to provide PM₁₀ and gaseous mass fluxes for the individual events. Table 3-5 presents a test plan for the open detonation tests.

Table 3-5. Test Plan for Open Detonation Sampling

Date	TNT	MPL	OP-LT	TEOM	OP-FTIR	UV-DOAS	Anemometer
3/22/2010	3*200 lb	X	X	X	X	X	X
	3*200 lb	X	X	X	X	X	X
3/23/2010	3*200 lb	X	X	X	X	X	X
	3*200 lb	X	X	X	X	X	X
3/24/2010	3*200 lb	X	X	X	X	X	X
	3*200 lb	X	X	X	X	X	X
3/25/2010	3*200 lb	X	X	X	X	X	X
	3*200 lb	X	X	X	X	X	X
3/26/2010	3*200 lb	X	X	X	X	X	X
	3*200 lb	X	X	X	X	X	X

3/27/2010	Spare						
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X = in-situ extractive and remote sampling will occur.

6,000 lbs of TNT is needed for this protocol. One series of three detonations is limited by the current pad size. Period is 5 to 15 s between detonations with 15 s preferable by the Range personnel. Each detonation is 65 ft apart and the 200 lb TNT safety distance is 1,919 ft (100 lb is 1,743 ft). Charges will be placed collinearly with the wind vector, to the extent predictable.

3.4 Sampling Methods and Other Critical Measurements

3.4.1 Wind Speed and Wind Direction

Anemometers will be located on a meteorological tower or on a scissor lift, depending on the availability of the meteorological tower. They will be operated at nominal heights of 5 ft (1.5 m) and 34 ft (10 m) above the ground.

3.4.2 Range-resolved Aerosol Backscatter Coefficient

The MPL will be operated in an air conditioned trailer that is located ~ 300 m downwind of the source of emissions and offset by another 500 m to account for the operating characteristics of the MPL. A reflective mesh will be located on the opposite edge of the plume to be used as a reference and allow for measurements of more optically thick plumes than is possible without the reflective mesh. The MPL will scan vertically along the entire cross-section of the plume to determine the back scatter coefficient of the aerosol in the plume. The range and time resolved back scatter coefficients will then be used to determine the extinction profiles for the aerosol in the plume as the plume passes through the measurement plane of the MPL. The MPL is calibrated based on the method developed by Ke Du (2007) Optical Remote Sensing of Airborne Particulate Matter to Quantify Opacity and Mass Emissions. Ph.D. Dissertation, University of Illinois, Urbana-Champaign.

3.4.3 PM₁₀ Mass Concentration

Mass concentrations of PM₁₀ will be measured continuously with two in-situ extractive TEOMs with real-time output describing those concentrations. Inlet heads for each TEOM will limit the upper particle diameter to PM₁₀ entering the samplers. The TEOM has a calibration procedure for the mass measurement and sample gas flow rate.

3.4.4 Path Integrated Aerosol Light Attenuation

Integrated path aerosol particle light attenuation will be measured using a custom OP-LT that will operate in a parallel path to the MPL. The OP-LT has a separate calibration procedure that is based on the optical properties of the OP-LT. The OP-LT is initially operated with the laser off to measure the instrument's dark current. The OP-LT is then run with the laser on continuously with the beam blocked at the exit to determine the baseline measurement. The OP-LT is then operated with modulated laser power on with beam block removed and no plume to measure the background light intensity (I_0). The OP-LT is then operated during a plume event to measure light intensity with the plume (I). The extinction is then measured as $1 - I/I_0$.

3.4.5 PICs of Detectable Gasses

The OP-FTIR method is an EPA approved method (TO-16). All data collection and analysis procedures will be according to the TO-16 method. All detected species will be quantified. The majority of gas-phase compounds have infrared absorption bands. An upper limit on the PIC value for any important but undetected combustion product can be determined from the standard error of the regression fit of the measured spectra to the calibrated reference spectra of the target species. The OP-FTIR spectra will be examined for outlier absorption bands to identify any gaseous compound that may be present in the plume. These could include compounds like carbon disulfide, carbonyl sulfide, and acetaldehyde and perhaps unstable transitional species.

The precision and accuracy of the concentration data may be checked by looking at the analyzed nitrous oxide concentrations. The known atmospheric background nitrous oxide concentration is around 315 ppbv (this is an average value, as the value exhibits a slight seasonal variation). The acceptable range of nitrous oxide concentrations will be 315 ppb \pm 25% for pathlengths of less than 50m, 315 ppb \pm 15% for pathlengths between 50 and 100m, and 315 ppb \pm 10% is for pathlengths greater than 100m. Verifying this background concentration provides a good QC check of the data collected. Obviously, this method is not valid for data collected at a site that is a source of nitrous oxide.

The Cerex open-path UV-DOAS is a bi-static, broadband, spectral absorption instrument designed to measure the concentration of various constituents in the open air along a path of up to approximately 100 to 200 m. The instrument is mounted on a tripod with data processing and control through a laptop computer. The Cerex instrument will be deployed for the purpose of acquiring mainly benzene, NO, NO₂, naphthalene, and, SO₂ spectral data for post processing. The UV-DOAS will measure nitric oxide (detection limit: 3 ppb), nitrogen dioxide (1 ppb). Table 3-6 provides MDL of the Cerex UV Sentry UV-DOAS over a 200-m path length and 1-min integration time. The Cerex UV Sentry instrument will be calibrated for benzene right after deployment using a known concentration 1-meter cell.

Table 3-6 Estimated UV DOAS MDLs for the Cerex UV Sentry sensor over a 200 m path length and 1-minute integration time.

Aromatic Species	MDL (ppb)
Benzene	7
Toluene	11
m-Xylene	16
o-Xylene	22
p-Xylene	6
Mesitylene	24

3.4.6 Solar Occultation

For assessment from the ground of the entire vertical OB/OD gas plume, a passive FTIR will use radiation from the sun as an infrared source by aiming the FTIR telescope through the plume directly at the sun. From the solar spectra it is possible to retrieve the path-integrated concentration (molecules/cm²) between the sun and the spectrometer. The concentration of the gases of interest is determined by looking at how the solar light is absorbed in the atmosphere. When measuring localized emissions, the background atmosphere is no longer of interest but instead low concentrations of emitted compounds at low altitudes are of interest. Calibrating the passive FTIR is similar to OP-FTIR with a desired accuracy of ±40%.

3.4.7 Emission Flux determination

The flux through the optical plane is determined from the product of the plume velocity and of the plane-integrated concentration determinations from the FTIRs (both active and passive), UV sensors, and the MPL plume-geometry extrapolation. PIC determinations for each gas-phase compound will be used to determine the plane-integrated concentrations, the concentration ratios to combustion-sourced CO₂ and to estimate the average plume concentrations.

3.5 List of Samples

- None

3.6 Sample Preservation Requirements

- None. There are no physical samples extracted from the field. However, the data acquisition system creates datasets that are uniquely identified/coded.

3.7 Numbering Method

All datasets will be coded with time stamps and defined based on the source of information for each sample (e.g., MPL-XXX, LT-XXX, TEOM-XXX, and anemometer-XXX).

3.8 Packing and Shipping

- None

4. QUALITY ASSURANCE/QUALITY CONTROL

4.1 Comparisons

As a QA check, the results obtained from integrated extractive sampling (i.e., EPA Flyer) and analysis by conventional methods will be compared to the corresponding continuous sampling techniques (i.e. MLT PM₁₀ and ORS gaseous measurement systems), when available.

4.2 Quality Objectives and Criteria

The objective of this project is to determine the feasibility of using the proposed measurement systems for characterizing the emissions from representative/simulated OB/OD events. The data quality objectives (DQOs) define the critical measurements (CM) needed to address the objectives of the test program, and specify tolerable levels of potential errors associated with data collection as well as the limitations of the use of the data. The different technologies used will be compared on the same basis using the same critical measurements whenever possible. A more detailed description of these comparisons can be found in Section 3.2.

The USEPA QAPP contains specific information about integrated extractive sampling QA/QC. The remainder of this section focuses on MLT PM₁₀ and ORS gaseous measurement system QA/QC. The following measurements are deemed to be critical to accomplish the project objectives:

- PM₁₀ mass derived values from TEOM
- Flow rate for TEOM
- Light attenuation across OP-LT path length
- Light attenuation across plume from MPL
- PICs of gasses detected by OP-FTIR, passive FTIR, and UV-DOAS
- Sampling time
- Wind speed
- Wind direction

These measurements are needed to determine the emission factors and emission rates for the various pollutants. The time sequence of sampling events must be recorded on the same time axis as are the extractive and path dependent measurements. This is essential to determine the extent of the emissions as a function of time for the different measurement platforms used by all members of the OB/OD measurement team.

4.3 Data Quality Indicator Goals for Critical Measurements

The data quality indicators (DQIs) are specific criteria used to quantify how well the collected data meet the DQOs. The DQI goals for the critical measurements correspond to and are consistent with the standards set forth in each respective referenced EPA Method when available. Accuracy and precision estimates are available where noted, and completeness goals for data collection and sampling are indicated in Table 4-1.

4.3.1 DQI Goals

The DQI goals for the MLT PM₁₀ and ORS gaseous sampling systems are listed in Table 4-1.

Table 4-1 Data Quality Indicators

Measurement Parameter	Analysis Method	Accuracy	Detection Limit	Completeness %
PM10 Concentration	TEOM	accuracy for mass measurement = $\pm 0.75\%$	0.06 $\mu\text{g}/\text{m}^3$ (1-hour average)	90
TEOM flow rate	Control system uses mass flow sensors and a measured ambient temperature and pressure to maintain a constant volumetric flow rate	99+%	3 l/min	100
Light attenuation across path length	OP-LT			
Light attenuation across plume	MPL			
PICs for Gases	OP-FTIR	$\pm 25\%$ of N2O atmospheric background	Variable Typically low ppb	90
PICs for Gases	UV-DOAS	$\pm 25\%$ of Calibrated Benzene	Variable Typically low ppb	90
PICs for Gases	Solar Occultation FTIR	$\pm 40\%$ of N2O atmospheric background	Variable Typically low ppb	90
Sampling Time	Computer clock	1' per month	2'	100
Wind direction	precision potentiometer	± 3 degrees	1 degree	Near 100
Wind speed	magnetically induced AC voltage	± 0.3 m/s or 1% of reading	1 m/s	Near 100

4.4 Assessing DQI Goals

In general, data quality indicator goals are based on either (1) published specifications, (2) related quantities (like drift for precision), or (3) engineering judgment based on previous experience with similar systems.

4.4.1 Precision

In order to measure precision, it is necessary to make replicate measurements of a relatively unchanging parameter. The ability to measure precision is dependent upon the type of data that is being measured. With an analytical balance or a CO analyzer, all it takes to measure precision is to measure the value of a reference standard more than once and compare the two numbers. To check precision, any pair of duplicate measurements can be entered into an equation of the form:

$$RPD = \frac{100 \times |Q - B|}{(Q + B) / 2}$$

Where:

Q = results from one run

B = results from second duplicate run

RPD = relative percent difference

If more than one pair of duplicate measurements is available, an entire population of individual precision can be generated. The best way to represent all of the replicate responses to a reference standard is with a relative standard deviation (RSD):

$$RSD = \frac{\sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}}{\sqrt{n-1} \bar{Y}}$$

This is often expressed as a percent.

When there are no reference standards, however, precision calculations are at the mercy of system stability. Furthermore, several of the measurements only generate one value per run (i.e., for 2 runs per condition, Precision = RPD). Therefore, for measurements that are compared to a reference standard, precision can be measured on a per-run basis as RPD. Overall precision for the entire test series can be expressed as RSD. For measurements that have no reference standard, precision is expressed as RSD for multiple measurements per run, and as RPD for singular measurements.

4.4.2 Accuracy

The accuracy of a measurement is expressed in terms of percent bias, or, in some cases recommended by the EPA standard methods, in terms of absolute difference. Percent bias is defined as:

$$\text{Percent Bias} = \frac{R - C}{C} \times 100$$

Where: R = instrument response or reading

C = calibration standard or audit sample value

Accuracy can take on the units of the measurement, it can be expressed as a percentage of the average measurement, or it can be expressed as a percentage of the measurement range.

4.4.3 Completeness

The ratio of the number of valid data points taken that meet DQIs goals to the total number of data points planned is defined as data completeness. All measured data are recorded electronically or on data sheets or project notebooks.

5. Assessment and Oversight

5.1 Assessments and Response Actions

Assessments are an integral part of a quality system. This project is assigned a QA Category IV and does not require planned technical systems and performance evaluation audits. However, should deficiencies be identified by any of the key individuals responsible, those deficiencies will be provided in the final report.. The report will discuss the problems and corrective actions taken.

5.2 Reports to Management

The final report prepared for this project will contain a discussion of QA procedures and an evaluation of the field experience and measurement results to determine the feasibility of the plume measurement systems.

5.3 Corrective Actions

Mark J. Rood is responsible for implementing corrective actions identified for work completed by UI. Ram Hashmonay is ultimately responsible for implementing corrective actions identified for work completed by ENVIRON.