NRMRL QUALITY ASSURANCE PROJECT PLAN

Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division

Determination of Forest Fire Intensity Effects on Emissions

EPA NRMRL Technical Lead Person: Brian Gullett, Ph.D.

Measurements Project, QA Category B

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Dr. Ray Carthy, USGS/UF
Dr. Bruce Quirk, USGS

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AED	Automated external defibrillator
AGL	Above ground level
BC	Black Carbon
CFS	Canadian Forestry Service
CO	Carbon monoxide
CO_2	Carbon dioxide
CoC	Chain of Custody
CPR	Cardiopulmonary resuscitation
DAQ	Data acquisition
DAS	Data acquisition system
DQI	Data Quality Indicator
EC	Elemental Carbon
EF	Emission Factor
EMS	Emergency Medical Services
EPA	U. S. Environmental Protection Agency
ER	Emission ratio
FI	Fire Intensity
HAZWOPER	Hazardous Waste Operations and Emergency Response
IR	Infrared
NDIR	Non-dispersive infrared
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute for Standards and Technology
OC	Organic Carbon
ORD	Office of Research and Development
PI	Principal Investigator
PM_{10}	Particulate matter equal to and less than 10 µm
POC	Point of Contact
QA	Quality Assurance
QAPP	Quality assurance project plan
RH	Relative Humidity
ROS	Rate of flame spread
RPD	Relative percent difference
RTP	Research Triangle Park
SD	Secure digital card
SEM	Scanning electron microscope
SOP	Standard Operating Procedures

SOW	Scope of Work
TC	Total Carbon
TTRS	Tall Timbers Research Station
UAV	Unmanned aerial vehicle
UDRI	University of Dayton Research Institute
UHF	Ultra High Frequency
USB	Universal serial bus
UF	University of Florida
USGS	U.S. Geological Survey
VHF	Very High Frequency
QAPP	Quality Assurance Project Plan

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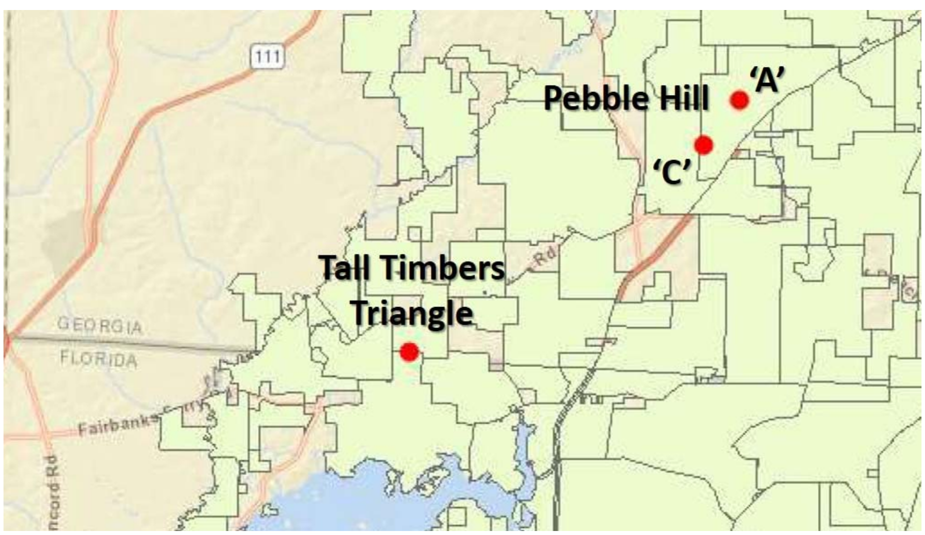
1 Project Description and Objectives

Fire plays an important role in the ecological landscape of the Southeastern United States, where prescribed burning is employed to manage more than 8 million acres of land every year. However, much remains to be learned about the physics of fire behavior and how fire dynamics relate to emission levels. Further, the health and climate implications of atmospheric particulate matter (PM) and aerosols released by wildfires and prescribed burns are not fully understood. This PM is well known to contain high levels of potentially toxic gases such as carbon monoxide, respirable soot particles, and organic compounds such as formaldehyde and furans. It may also contain, depending upon the vegetation type, burn intensity, and underlying soil mineralogy, ash with caustic alkali salts and various heavy metals, and plume-entrained soil minerals such as asbestos fibers.

To learn more about these issues, a U.S. Geological Survey (USGS) team has successfully proposed a USGS-internal Innovation Fund project and has enlisted the University of Florida – Gainesville (UF), the Canadian Forestry Service (CFS), and the EPA/Office of Research and Development (ORD) to participate in a field sampling effort during a prescribed burn. The USGS grantee, UF, will participate by flying their Unmanned Aerial Vehicle (UAV), while carrying an infrared (IR) sensor and ORD's emission sensor/samplers. This system will monitor surface temperatures and the spread of wildland fires from above and below the forest canopy using IR remote sensing at multiple spatial scales. The IR sensor system will provide data to be analyzed by CFS and the emission data will be analyzed by ORD in conjunction with USGS.

The project will use a multicopter UAV to measure and correlate fire intensity and rate of spread with the type and amount of emissions from a prescribed burn. IR imagers provide images of temperature, where each pixel provides essentially the same data as a thermocouple at that point. Geo-referenced imagery provides spatially-explicit data to compute rate of flame spread (ROS) by tracking the position of the flame front from one frame to another and measuring the distance traveled at each perimeter pixel normal to the flame. In combination with new IR sensing capabilities and miniaturized pollutant sensors/samplers, development of UAV technology offers a game-changing capability to extensively characterize fire dynamics and associated emissions. UAVs, particularly multicopters, can systematically deploy over a study area in order to examine how fire intensity (FI) and ROS respond to different fuel types and different levels of fuel accumulation and how those variables dictate the type and amount of emissions. Though IR measurement of ROS has been demonstrated, the use of a small UAV platform remains novel and promises to significantly and effectively supplant ground- and airplane-based measurements while simultaneously reducing costs. Companion measurements of combustion characteristics will be determined including combustion efficiency (CO, CO_2), related burn quality measures such as black carbon (EC) in particulate matter, and the chemical and mineralogical makeup of the particulate matter. Our proposed method has the advantage of directly relating fire dynamic characteristics with combustion quality, the latter which has been directly related to emissions. Since the open burning of vegetative fuels is a highly incomplete combustion process, owing primarily to the fuel moisture and non-ideal access of oxygen, these simultaneous suite of measurements will be critical toward understanding their interactions. These measurements will also help understand what sorts of elemental and mineral toxicants might be present in wildfire particulate matter (PM).

USGS has been looking at ash composition from wildfires and prescribed burns for a number of years but has never sampled the smaller particulate matter fractions or the gases. In this project USGS hopes to better understand the relationship between the intensity of the fire and what type of particulates come off of it. USGS has done ground-based sampling and shown with water leach tests and simulated lung fluid tests (mixing ash with water and simulated lung fluid) that very high alkaline pH's result. White ash is usually produced from high burn intensity fires and is the result of the complete combustion of organic material. The whiter the ash the more alkaline the test result. USGS is also interested in the soil/mineral particles released during a fire. There are a number of naturally occurring minerals that are potentially toxic when inhaled and could be potentially released from a wildfire. USGS has a field emission scanning electron microscope (SEM) that has an imaging resolution of 10 nanometers (chemical resolution of 2 microns) the will be used to characterize the filter PM.



This work will involve a 1-week series of tests at Tall Timbers Research Station in northern Florida with measurements commencing Wednesday, April 19, weather permitting. The target burn areas are comprised of four ¾ acre plots at Pebble Hill (4-year rough, Longleaf Pine and Wiregrass stand) and one 9 acre plot at Tall Timbers (2-year rough, Loblolly and various shrubs). See http://www.gis.ttrs.org/viewer/ near the Florida/Georgia border, just north of Lake Lamonia. See map.

The data derived from ORD's work will consist of emission factors that relate a particular analyte or pollutant to the fuel.

The objectives of these tests are to

- Demonstrate the use of a UF-operated UAV to conduct aerial sampling on prescribed burns, coupling CFS IR measurements with ORD emission measurements, relating measures of fire dynamics to emission factors
- To gather PM samples for USGS compositional analysis

2 Organizations and Responsibilities

2.1 Organizations and Mechanisms

This research effort is comprised of participants from the U.S. Geological Service, U.S. EPA/ORD, University of Florida (Gainesville), University of Dayton Research Institute (UDRI), and the Canadian Forestry Service (CFS). USGS is funding the other four participants through Interagency Agreements, Invitational Travel, and a Cooperative Agreement. The field effort is hosted by Tall Timbers Research Station (TTRS – talltimbers.org) operated by the Land Conservancy, one of the nation's primary land trusts. Personnel and Responsibilities are included below.

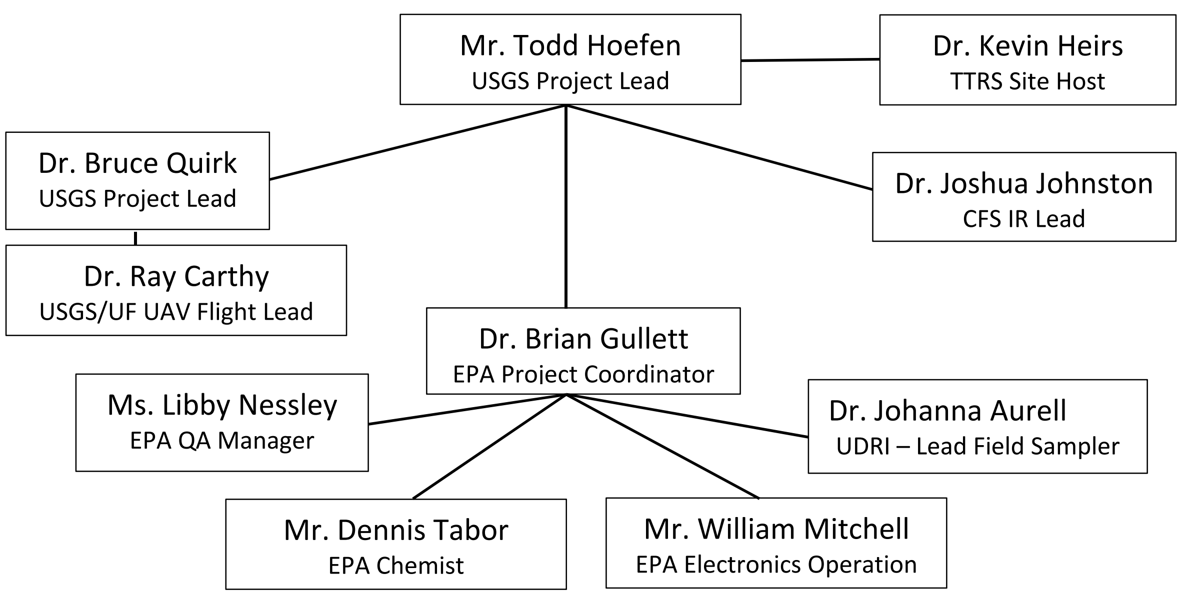


Figure 2-1. Organization Chart.

Table 2-1. Site and Project Personnel.

Name	Organization	Responsibility	Contact Information
Dr. Brian Gullett	EPA/ORD	Project Coordinator, EPA Air Sampling Team	919-541-1534 office 919-699-3074 cell gullett.brian@epa.gov
Ms. Libby Nessley	EPA/ORD	EPA QA manager	919-541-4381, nessley.libby@epa.gov
Dr. Johanna Aurell	UDRI	Lead Field Sampler	919-541-5355, aurell.johanna@epa.gov
Mr. Dennis Tabor	EPA/ORD	Chemist, sample transmittal methods, analyses	919-541-2686, tabor.dennis@epa.gov
Mr. Bill Mitchell	EPA/ORD	Electronics operations	919-541-2515, mitchell.bill@epa.gov
Mr. Todd Hoefen	USGS	Project Lead	303-870-4516 cell, thoefen@usgs.gov
Dr. Bruce Quirk	USGS	Project Manager	quirk@usgs.gov
Dr. Ray Carthy	USGS/UF	UAV flight lead	352-846-0545, ngosi@ufl.edu
Dr. Joshua Johnston	CFS	IR Lead	705-541-5548, Joshua.johnston@canada.ca
Dr. J. Kevin Hiers	TTRS	Site Host	229-560-8861 cell, jkhiers@ttrs.org

The Site Host is Dr. Kevin Hiers (TTRS). Dr. Brian Gullett will be responsible for ORD team coordination and inter-team coordination as well as being a group liaison with Dr. Hiers. Dr. Johanna Aurell (UDRI) is the chief operator of the sampling system, and is responsible for field sampling instruments. Dr. Aurell , as Sampling Lead, will conduct equipment checks prior to shipment including pump flows and gas calibration checks. She will be the lead sample and data custodian in the field and will be responsible for downloading, storing, and reducing the instrumental data for analysis. Mr. Tabor will be responsible for coordinating, obtaining, reviewing, and validating external laboratory analyses, if any. Mr. Mitchell will be responsible for sampler system design and function. Mr. Hoefen is the USGS lead who will coordinate the various agencies. Dr. Quirk is the USGS PI for UF. Dr. Carthy's team will fly the UAV, coordinating with their pilot and other on-site UAV operators. Dr. Johnston will obtain and analyze IR data during the fire. Ms. Libby Nessley is the EPA QA manager and will review this QAPP as well as any products derived herein produced solely or in part by ORD.

2.2 ORD On-Site Personnel

EPA team personnel on site include, Drs. Gullett and Aurell, and Mr. Mitchell. All personnel have completed the EPA field safety training. Dr. Gullett is CPR/AED certified. Both Drs. Gullett and Aurell are HAZWOPER certified. For more details on EPA personnel qualifications and safety see the "Safety, Health, and Environmental Management Protocol for Field Activities" for this project.

3 Project Schedule and Milestones

Table 3-1. Project Schedule.

Milestone	Date
Submit QAPP for review	April 4, 2017
QAPP approval	April 14, 2017
Personnel and equipment depart from RTP	Monday, April 17, 2017
Site arrival TTRS, 0730	Tuesday, April 18, 2017
Daily briefings, TT Barn 0730	Every day
Equipment preparation, UAV trials	Tuesday, April 18, 2017
Sampling begins, weather permitting	Wednesday, April 19, 2017
Sampling complete (PM), equipment packed	Sunday, April 23, 2017
Personnel departure for RTP (AM)	Monday, April 24, 2017
Chain of custody, samples transferred	Thursday, April 26, 2017
Sample analysis complete (ORD)	Monday, May 22, 2017
Draft report to USGS on emissions	Monday, July 17, 2017

The results from this project will be documented in a draft report to USGS and potential journal article(s). The Report will undergo review according to the procedures of the respective organizations appropriate for the intended audience. Results may be presented by any participant with mutual approval at related symposia or in peer review journal formats.

4 Method

4.1 Emission Sampling

ORD will sample for CO, CO_2, and filter-based PM_{10}. If the payload of the UF UAV allows, ORD will also sample for OC/EC quartz filters and black carbon. CFS will sample IR using a Microepsilon TIM400 camera (Microepsilon Messtechnik, Ortenburg, Germany). UF will fly their octacopter, an eight-rotor DJI S1000 (DJI, Shenzhen, China). PM_{10} emission factors will be determined using the common carbon balance method whereby the target analyte is co-sampled with CO and CO_2, a ratio of the analyte mass to carbon mass is determined, and this value is scaled to the carbon mass in the original test material. For example, 1 g of PM_{10} is sampled along with 5 g of carbon as CO and CO_2. Commonly a carbon fraction of 0.5 is assumed for biomass. The emission factors would be 1 g of PM_{10} divided by 5 g of carbon * (1 g carbon/2 g biomass) = 0.1 g of PM_{10} per g of biomass burned.

4.2 Site Location

The sampling site office is located at the Tall Timbers Research Station in Florida, north east of Tallahasee near to 30°39’20.52” N, 84°12'32.52"W. This is about a 22 min drive from northeast Tallahasee.

4.3 Test Sites

The target burn areas are comprised of four ¾ acre plots at Pebble Hill (4-year rough, Longleaf Pine and Wiregrass stand) and one 9 acre plot at Tall Timbers (2-year rough, Loblolly and shrubs). See map above for locations.

4.4 Target Analytes

The target analytes are listed in Table 4-1.

Table 4-1. Sampling Target Analytes and Number of Samples.

Analyte	Instrument/Method	Frequency	Minimal # of Samples for Each Plot
CO_2	Sunset NDIR[a]/10A[1]	Continuous	Continuous
CO	Electrochemical cell/3A[2]	Continuous	Continuous
PM_{10}[b]	Impactor, Teflon filter, Gravimetric/40 CFR Part 50, Appendix J[3]	Batch	1
Black Carbon	MicroAethalometer, AE51/52, MA200	Continuous	Continuous
EC/OC/TC[c]	Quartz filter/NIOSH Method 5040 [4]	Batch	1

[a]Non-dispersive infrared. [b]Fine particles in the ambient air with particles less than or equal to 10 µm in diameter and Total PM. [c]Elemental carbon/ Organic carbon/Total Carbon

Efforts will be made to gather the minimum number of samples as indicated in Table 4-1 of each batch emission constituent to provide for statistical confidence. As time, site logistics, weather, and sampling dictate, additional samples will be taken.

Background, ground-level samples will be taken in a location that is not downwind of the burn site, vehicles, etc. Field blanks and laboratory blanks will be analyzed as appropriate.

4.5 Sampling Instruments

Air sampling will be accomplished while UF maneuvers their ground-controlled UAV, specifically an eight-motor multicopter (octacopter), into the plume with the EPA/ORD sampling system called the "Kolibri-Lite"(see Zhou et al. [5]).

4.6 Radio frequencies

The EPA Kolibri samplers use an Xbee Digimesh network (Digi International, Minnetonka, MN, USA). The amount of Xbee transceivers deployed depends upon range from the base station to the Kolibri. The specs for each Xbee transceiver are frequency: 2.4 GHz ISM; transmit power: 63 mW (+18 dBm). Several antenna types are deployed ranging from 2 db to 7db gain. More information can be found at http://www.digi.com/products/xbee-rf-solutions/modules/xbee-digimesh-2-4#specifications (last accessed April, 2017).

Motorola Ultra High Frequency/Very High Frequency (UHF/VHF) radios are used for flight operations, sampler coordination, and in-field observer communications/safety. The radios are XPR3500 models with 4.5W, UHF: 1W/4W, VHF:1W/5W (see Figure 4-1).

PRODUCT SPEC SHEET
MOTOTRBO™ XPR 3000 SERIES PORTABLE RADIOS

RECEIVER	VHF	UHF
Frequencies	136-174 MHz	403-512 MHz
Channel Spacing	12.5 kHz / 25 kHz*	
Frequency Stability	± 0.5 ppm	
Analog Sensitivity (12dB SINAD) Typical	0.3uV 0.22uV (typical)	
Digital Sensitivity	5% BER @ 0.25uV (0.19uV typical)	
Intermodulation (TIA603D)	70 dB	
Adjacent Channel Selectivity (TIA603A)-1T	60dB @ 12.5 kHz / 70dB @ 25 kHz*	
Adjacent Channel Selectivity (TIA603D)-2T	45dB @ 12.5 kHz / 70dB @ 25 kHz*	
Spurious Rejection (TIA603D)	70 dB	
Rated Audio	0.5W	
Audio Distortion @ Rated Audio	5% 3% (typical)	
Hum and Noise	-40dB @ 12.5 kHz / -45dB @ 25 kHz*	
Audio Response	TIA603D	
Conducted Spurious Emission (TIA603D)	-57 dBm	

ENVIRONMENTAL SPECIFICATIONS: DISPLAY XPR 3500 & NON-DISPLAY XPR 3300

TRANSMITTER	VHF	UHF
Frequencies	136-174 MHz	403-512 MHz
Channel Spacing	12.5 kHz / 25 kHz*	
Frequency Stability	± 0.5 ppm	
Low Power Output	1W	1W
High Power Output	5W	4W
Modulation Limiting	± 2.5 kHz @ 12.5 kHz ± 5.0 kHz @ 25 kHz*	
FM Hum and Noise	-40 dB@ 12.5 kHz -45 dB@ 20/25 kHz*	
Conducted/Radiated Emission	-36 dBm < 1 GHz -30 dBm > 1 GHz	
Adjacent Channel Power	60 dB @ 12.5 kHz 70 dB @ 25 kHz*	
Audio Response	TIA603D	
Audio Distortion	3%	
4FSK Digital Modulation	12.5 kHz Data: 7K60F1D & 7K60FXD 12.5 kHz Voice: 7K60F1E & 7K60FXE Combination of 12.5 kHz Voice and Data: 7K60F1W	
Digital Vocoder Type	AMBE+2™	
Digital Protocol	-ETSI TS 102 361 -1,-2,-3	

Figure 4-1. Motorola communication radio specifications.

4.7 External analyses

PM_{10} gravimetric analyses will be performed by Chester LabNet. Dr. Aurell will prepare Chain of Custody sheets and Dennis Tabor (ORD) will be in charge of the sample transfer, data review, and validation of the laboratories' reports. The returned samples will be sent to USGS, Mr. Todd Hoefen, for USGS to conduct their compositional analyses.

4.8 Flight Operations

Aerial sampling will be conducted by a UAV operated by a USGS Grantee, UF, at a height of less than 400 feet and within visual range. Observers in radio communication will allow for visual observation of the plume

4.9 Sample Identification

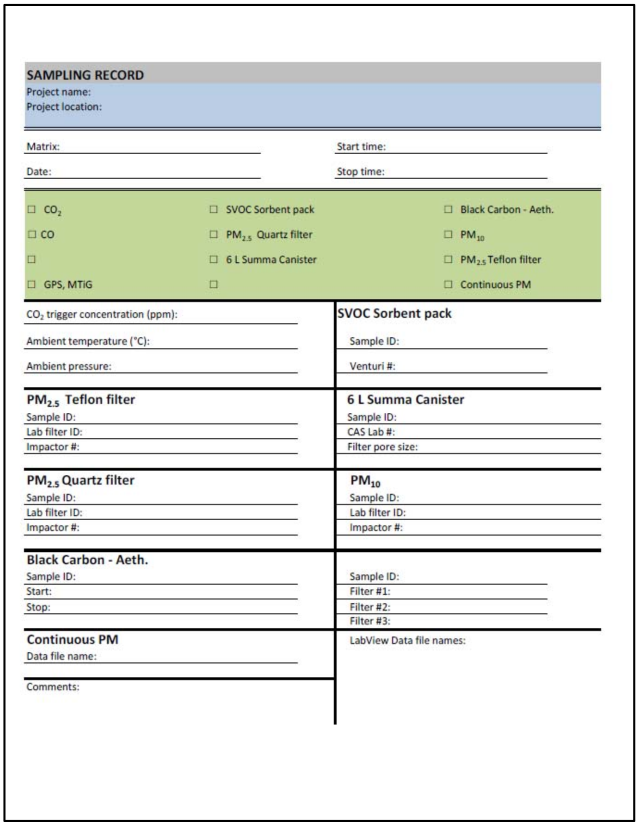
Each sample data sheet and sample fraction will be given an identifying code number that will designate the run number (Table 4-2). The codes and code sequence will be explained to the field team and laboratory personnel to prevent sample mislabeling. Proper application of the code will simplify sample tracking throughout the collection, handling, analysis, and reporting processes.

The Kolibri data sets and all derivative data sets will be retained by Dr. Gullett. All primary and secondary data will be retained in duplicate by Dr. Brian Gullett who will create a file folder on the EPA server in the L drive, Public, GullettResearchUpdates labeled "raw data" to preserve all of the raw data files collected and separately store any copies and/or derivative files in a "data analysis" folder.

The matrix, start and stop time, data logging file name, sample ID, filter ID, and PM filter type , for each burn will be recorded on a Sampling Record form (Figure 4-2). For each collected target compound sample a Sample Chain of Custody (CoC) (Figure 4-3) sheet will be generated. The CoC forms will be initiated and maintained by Dr. Aurell and in duplicate by Mr. Dennis Tabor, Chemist.

Table 4-2. Sample Nomenclature.

AA-CC-DDD-MMDDYY-EE-FF		
	Sample Code example	**Code definition**
AA	TB	Test condition (TB = Trip blank, PL = Plume Sample, BS = Background Field Sample)
CC	PM	Sampling Media (PM = Particulate Matter Filter)
DDD	TT3	Tall Timbers, plot number
MMDDYY	071517	Date Field, month/day/year
FF	01	Sample Number (01, 02, 03, etc.)


SAMPLING RECORD
Project name:
Project location:

Matrix:
Start time:
Date:
Stop time:

☐ CO_2
☐ SVOC Sorbent pack
☐ Black Carbon - Aeth.
☐ CO
☐ $PM_{2.5}$ Quartz filter
☐ PM_{10}
☐
☐ 6 L Summa Canister
☐ $PM_{2.5}$ Teflon filter
☐ GPS, MTiG
☐
☐ Continuous PM

CO_2 trigger concentration (ppm):
Ambient temperature (°C):
Ambient pressure:

SVOC Sorbent pack
Sample ID:
Venturi #:

$PM_{2.5}$ Teflon filter
Sample ID:
Lab filter ID:
Impactor #:

6 L Summa Canister
Sample ID:
CAS Lab #:
Filter pore size:

$PM_{2.5}$ Quartz filter
Sample ID:
Lab filter ID:
Impactor #:

PM_{10}
Sample ID:
Lab filter ID:
Impactor #:

Black Carbon - Aeth.
Sample ID:
Start:
Stop:

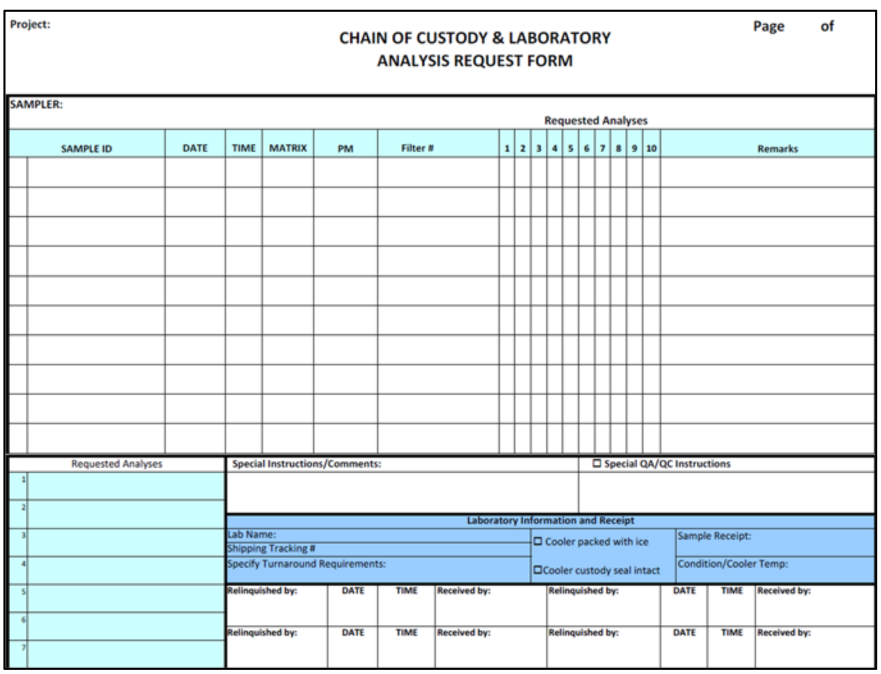
Sample ID:
Filter #1:
Filter #2:
Filter #3:

Continuous PM
Data file name:

LabView Data file names:

Comments:

Figure 4-2. Sampling Record Form, Example Only.


Project:
CHAIN OF CUSTODY & LABORATORY ANALYSIS REQUEST FORM
Page of

SAMPLER:

Requested Analyses

SAMPLE ID	DATE	TIME	MATRIX	PM	Filter #	1	2	3	4	5	6	7	8	9	10	Remarks

Requested Analyses
1
2
3
4
5
6
7

Special Instructions/Comments:
☐ Special QA/QC Instructions

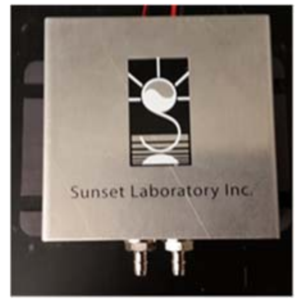
Laboratory Information and Receipt
Lab Name:
Shipping Tracking #
Specify Turnaround Requirements:
☐ Cooler packed with ice
☐Cooler custody seal intact
Sample Receipt:
Condition/Cooler Temp:

Relinquished by:	DATE	TIME	Received by:	Relinquished by:	DATE	TIME	Received by:
Relinquished by:	DATE	TIME	Received by:	Relinquished by:	DATE	TIME	Received by:

Figure 4-3. Chain of Custody Form, Example Only.

5 Measurement and Quality Assurance Procedures

5.1 CO_2 Measurements



The carbon balance method for determining emission factors requires a comparison of the amount of carbon sampled in the plume versus that in the original fuel. The majority of the carbon is present as CO_2. The system CO_2 sensor (DX62210/DX6220 OEM Model, RMT Ltd, Moscow, Russia) measures CO_2 concentration by means of infrared absorption (NDIR). Sensor output voltage is linear from 200 to 2000 ppm. The DX62210/DX6220 will be calibrated in the EPA Metrology Laboratory prior to departure at 0 to 2000 ppm with ± 2 ppm error using EPA Method 3A[2]. A particulate filter precedes the optical lens. The DX62210/DX6220 will be calibrated for CO_2 on a daily basis in accordance with EPA Method 3A[2]. The DX62210/DX6220 CO_2 concentration will be recorded on the Teensy a USB-based microcontroller board using an Arduino-generated data program. CO_2 background samples will be taken daily prior to sampling.

CO_2 from AirGas (ca. 4500 ppm) will be used for calibration. All gas cylinders used for calibration are certified by the suppliers that they are traceable to National Institute of Standards and Technology (NIST) standards. A precision dilution calibrator Serinus Cal 2000 (American ECOTECH L.C., Warren, RI, USA) will be used to dilute the high-level span gases for acquiring the mid-point concentrations for the e2V EC4-500-CO calibration curves.

Table 5-1. CO_2 Quality Information.

Target Compound	Measurement/ Analytical Method	Sampling Rate	QA/QC Check Procedure	QA/QC Check Frequency	Acceptance Criteria/DQIs	Reference Standard	Corrective Action	Preservation/ Storage
Carbon dioxide	NDIR CEM DX6210 or DX6220 [2]	Every second	3 point zero & calibration drift test	1 per sample, daily in field	±5% of span	Certified CO_2 calibration gases	Re-calibrate monitor	L: drive storage

5.2 CO Measurements

The CO sensor (e2V EC4-500-CO) is an electrochemical gas sensor (SGX Sensortech Ltd, High Wycombe, Buckinghamshire United Kingdom) which measures CO concentration by means of an electrochemical cell through CO oxidation and changing impedance. The E2v CO sensor has a CO detection range of 1-500 ppm with resolution of 1 ppm and sensitivity of 55-85 nA/ppm. The temperature and relative humidity (RH) operating range is -20 to +50 °C and 15 to 90% RH, respectively. The response time is less than 30 seconds. Output is non-linear from 0 to 500 ppm. A calibration curve has been calculated in the EPA Metrology Laboratory at 0 to 100 ppm with ± 2 ppm error using U.S. EPA Method 3A [1]. The sensor will be calibrated for CO on a daily basis in accordance with U.S. EPA Method 3A [2]. The sensor has a weight of approximately 5 g. The storage life of the CO sensor is six months based on the manufacturer's printed recommendation; after that time the sensor is replaced. The e2V CO concentration will be recorded on the Teensy a USB-based microcontroller board using an Arduino-generated data program. CO background samples will be taken daily prior to sampling.

CO from AirGas (ca. 100 ppm) will be used for calibration. All gas cylinders used for calibration are certified by the suppliers that they are traceable to NIST standards. A precision dilution calibrator Serinus Cal 2000 (American ECOTECH L.C., Warren, RI, USA) will be used to dilute the high-level span gases for acquiring the mid-point concentrations for the e2V EC4-500-CO calibration curves.

Table 5-2. CO Quality Information.

Target Compound	Sampling/ Measurement/ Analytical Method	Sampling Rate	QA/QC Check Frequency	QA/QC Check Procedure	Acceptance Criteria/DQIs	Reference Standard	Corrective Action	Storage
Carbon monoxide	CEM/E2v EC4-500-CO Electrochemical cell[1]	Every second	1 per sample, daily in field	3 point zero & calibration drift test	±5% of span	Certified CO calibration gases	Re-calibrate monitor	L: drive storage

5.3 Particulate Matter

5.3.1 PM10

PM_{10} will be sampled with SKC impactors (761-203B) using 37 mm tared Teflon filter (Chester LabNet) with a pore size of 2.0 µm via a constant micro air pump (C120CNSN, Sensidyne, LP, St. Petersburg, FL, USA) of 10 L/min. PM_{10} will be measured gravimetrically following the procedures described in Appendix J, 40 CFR Part 50[3]. Particles larger than 10 µm in the PM_{10} impactor will be collected on a greased impaction disc mounted on the top of the first filter cassette. The constant flow pump will be calibrated with a Sensidyne Go-Cal Air Flow Calibrator (Sensidyne LP, St. Petersburg, FL, USA).

The pre-weighed Teflon filters will be obtained from Chester Lab net. The analytical balance used to weigh filters shall be suitable for weighing the type and size of filters and have a readability of ±10 µg. 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 weighing. Both the pre- and post-sampling weighing 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 sampling period. The post-sampling conditioning and weighing shall be completed within 30 days after the end of the sample period. Sampled filters are returned to the filters' petri-dish and sealed with Teflon tape. The petri-dishes are stored in separate Zip-Lock bags with desiccant. The Zip-Lock bags are marked with the sampling information e.g. filter number, petri-dish number, sampling date. Filter samples are shipped to the laboratory separate from bulk samples. Background samples will be taken for analysis.

Table 5-3. PM_{10} Filter Sampling Information.

Target Compound	Sampling/Measurement/ Analytical Method	Sampling Rate	Sample Handling	Preservation/ Storage	Hold Time	Laboratory
PM_{10}	37 mm Teflon Filter/gravimetric/40 CFR Part 50 Appendix J [3]	10 L/min	1 filter in one petri dish/ sample	desiccator	30 d	Chester LabNet

Table 5-4. PM_{10} Filter Sampling Quality Information.

Measured Parameter/Method	QA/QC Check Procedure	Reference Standard(s)	QA/QC Check Frequency	Acceptance Criteria/ DQIs	Corrective Action
PM_{10} Concentration/analytical balance	Gas pump flow calibration with a Go-Cal Sensidyne calibrator, filter blanks, balance calibration	Sensidyne Go-Cal Air Flow Calibrator, ASTM Class 1 weights	Flow meter prior to and 1x during sampling trip	±5% of 10 L/min, ±30 ug, 80% completeness of samples for 5 plots	Re-calibrate gas pump, check for contamination, re-calibrate balance

5.4 Black Carbon

As the payload capacity of the UAV allows, BC will be measured with an AE51, AE52 or MA200 (Aethlabs, San Franscisco, CA USA). The MicroAethalometer is a small, portable, hand-held instrument capable of measuring black carbon (BC) concentration, the AE-52 can also measure UV PM, as defined by the manufacturer. The MA200 can measure BC as well as light absorbing PM at four other wavelengths: 880 nm (BC), 625 nm, 528 nm, 470 nm, and 375 nm (UV PM). These instruments determine the BC concentration at 880 nm by absorption (the AE-52 also uses 370 nm for UV PM). The AE-51/52 has the physical dimensions of 117 mm x 66 mm x 38 mm and weighs approximately 250 g. The MA200 has physical dimensions of 136.7 mm x 85 mm x 35.75 mm and weighs 400 g. The MA200 is larger and heavier than the AE instruments, but has multiwavelength measurement capability and multiple filter spots, which extends the measurement time. The AE-51 and MA200 instruments are capable of sampling in increments of 1, 60, or 300 seconds from 0-1 mg BC/m^3, while the AE-52 has increments of 10, 60 or 300 seconds. The optical response of these instruments is factory-calibrated. The pump flow is calibrated before leaving for the field via a Sensidyne Go-Cal Air Flow Calibrator (Sensidyne LP, St. Petersburg, FL, USA). For the AE-51/AE-52 instruments, as the coupon gets clogged during sampling, the flow decreases but is logged throughout. A red light alarm indicates when the pressure drop across the coupon is excessive, and the coupon needs to be changed out. The MA200 will advance to a new filter spot when the pressure drop becomes excessive. Integrated filter samples will be taken at each measurement location and stored for gravimetric or thermal-optical analysis.

Table 5-5. Carbon Sampling Information

Target Compound	Measurement/Analytical Method	Sampling Rate	Measurement resolution	Measurement precision	Flow rate	Storage
Black Carbon	Microaethalometer (AE51)/change in attenuation of transmitted light due to continuous collection of aerosol deposit on filter	1, 60 or 300 seconds	0.001 µg BC/m^3	±0.1 µg BC/m^3, 1 min avg., 150 mL/min flow rate	50, 100, 150 mL/min	L: drive storage
Black Carbon, UV PM	Microaethalometer (AE52)/change in attenuation of transmitted light due to continuous collection of aerosol deposit on filter	10, 60 or 300 seconds	0.001 µg BC/m^3 0.001 µg UVPM/m^3	±0.1 µg BC/m^3, 1 min avg., 150 mL/min flow rate	50, 100, 150 mL/min	L: drive storage
Light absorbing carbon (880 nm, 625 nm, 528 nm, 470 nm, 375 nm)	Microaethalometer (MA200)/change in attenuation of transmitted light due to continuous collection of aerosol deposit on filter	1, 5, 10, 30, 60 or 300 seconds	0.001 µg BC/m^3	±0.1 µg BC/m^3, 1 min avg., 150 mL/min flow rate	50, 100, 150 mL/min	L: drive storage

5.4.1 *Elemental Carbon, Organic Carbon and Total Carbon*

OC/EC/TC will additionally be sampled with an SKC $PM_{2.5}$ impactor using a 37 mm quartz filter via a constant micro air pump (C120CNSN, Sensidyne, LP, St. Petersburg, FL, USA) of 10 L/min. Particles larger than 2.5 µm in the $PM_{2.5}$ impactor will be collected on an oiled 25 mm impaction disc mounted on the top of the first filter cassette. The constant flow pump will be calibrated with a Sensidyne Go-Cal Air Flow calibrator (Sensidyne LP, St. Petersburg, FL, USA). The OC/EC/TC will be analyzed via a modified thermal-optical analysis (TOA) using Modified NIOSH Method 5040 [4]. Background samples will be taken for analysis.

Table 5-6. OC/EC/TC Quality Information.

Measured Parameter/Method	QA/QC Check Procedure	Reference Standard(s)	QA/QC Check Frequency	Acceptance Criteria/ DQIs	Corrective Action
OC/EC using Modified NIOSH Method 5040 [4]					
gas volume	Run internal standard in instrument calibration loop	CH_4/He	Each time the CH4 tank is changed	Each determination (n = 3) is within 3%	re-enter new volume in instrument software
Readiness for quantification	single point calibration bracketing the expected concentration range; midpoint standard check	Sucrose solution	Daily	within 7% of the spiked concentration of sucrose solution	repeat calibration; prepare new sucrose solution; check gas flows and general instrument operation
System blank	Run blank	blank	Daily and at the end of each run as necessary	<0.1 µg C/cm^2	redo instrument blank or complete an oven bakeout
Instrument precision	Run standard solution	Sucrose solution	Daily	within 5% of previous analysis results	re-spike and analyze; warm-up FID
Precision of sample analysis (n = 2)	Sample repeat, one every 10 samples	Sample repeat	As needed programmatically and as sample mass allows	±15%	re-analyze sample; check calibration precision

5.5 Kolibri Data Acquisition System and Data Storage

The Kolibri's data acquisition system (DAS) consist of an onboard Teensy universal serial bus (USB)-based microcontroller board (Teensy 3.1, PJRC, LLC., Sherwood, OR, USA) running an Arduino based data acquisition and control program ("TeensyDAQ"). The main assignment for the TeensyDAQ is power regulation, data logging, and data transmission. The power control circuit on the Teensy board provides a regulated voltage for all the electrical components in the sensor package. Also included in the DAS is a ground based computer which is running

"KolibriDAQ" a Labview generated data acquisition and control program, which is used to view live data and run/control the onboard TeensyDAQ via a XBee wireless network (Xbee S1B, Digi International, Inc., Minnetonka, MN, USA) (see Figure 5-1 below). The KolibriDAQ is capable of plotting real time CO_2 and CO data, display sampling time, and performing on the fly calculations to estimate the total amount of gaseous carbon sampled for the energetic sample.

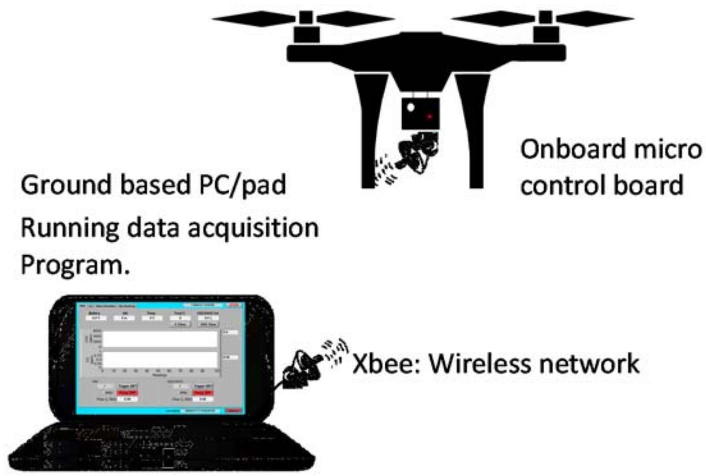


Figure 5-1. Schematic of Data Acquisition System, not to scale.

All raw data will be time stamped, and written to a standard secure digital (SD) card on the onboard TeensyDAQ at a rate of one sample per second (1 Hz). Visual indicators for station-to-station communications and data logging will be checked and downloaded to computers periodically during the test. At the end of each test, the micro SD memory cards will be transferred from the SD cards to external hard drives via a laptop computer with a Universal Serial Bus (USB) port. The SD cards will also be checked for valid data and labeled for physical archive with project name, date, and time. Data will also be uploaded to EPA's managed servers for archive and accessibility. Data files are in tab delimited text files and are thus easily imported into common spreadsheet/database analysis programs (*e.g.* MS Excel and Origin). Electronic data and pictures will be posted in the folder L:\Lab\NRML_Public\GullettResearchUpdates\ on the EPA network share drive upon return from the field or as they are generated or received.

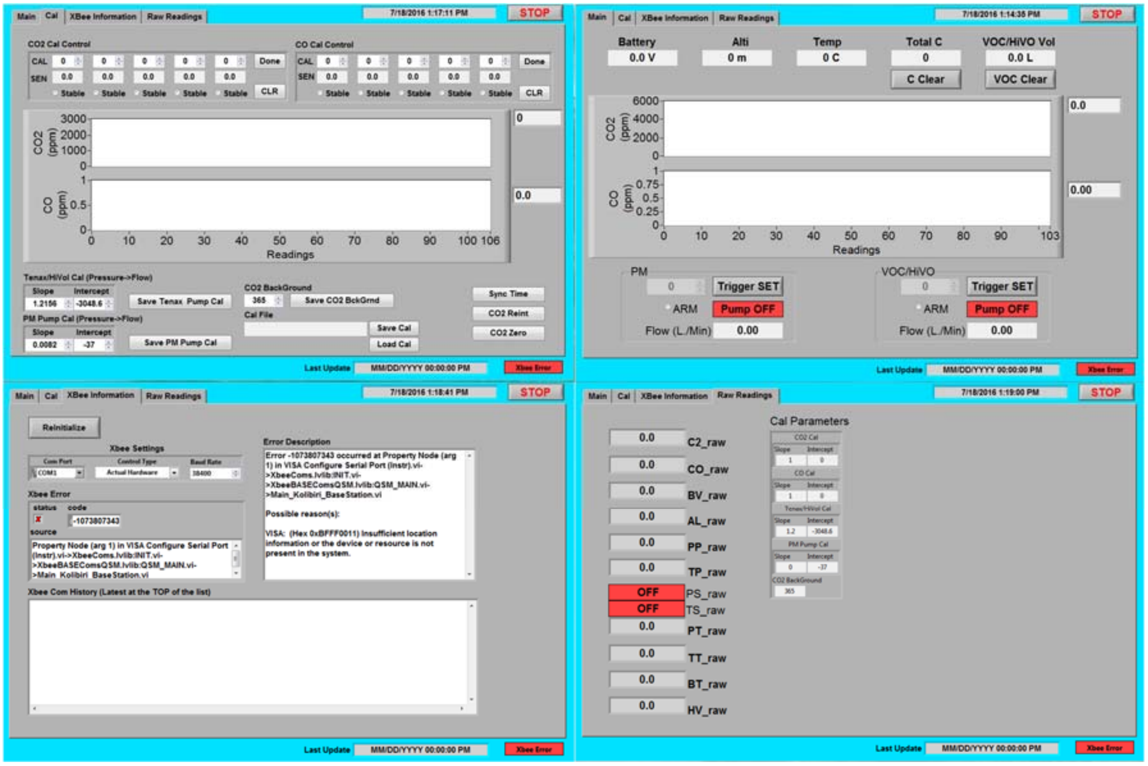


Figure 5-2. KolibriDAQ interface windows: Run, Calibration, Xbee wireless network information, and raw data readings.

6 Data Analysis, Interpretation, and Management

The determination of emission factors, mass of pollutant per mass of fuel burned, depends upon foreknowledge of the fuel composition, specifically its carbon concentration. The carbon in the fuel is presumed for calculation purposes to proceed to either CO_2 or CO, with the minor carbon mass in hydrocarbons and PM ignored. Concurrent emission measurements of pollutant mass per carbon (as CO_2 + CO) can be used to calculate total emissions of the pollutant from the fuel using its carbon concentration.

The emission ratio of each species of interest will be calculated from the ratio of background-corrected pollutant concentrations to background-corrected carbon dioxide concentrations. Emissions factors will be calculated using these emissions ratios following the carbon balance method [6] shown in equation 1.

$$EF_i = f_c \frac{ER_i}{\sum_j \frac{\Delta C_j}{\Delta CO_2}} \qquad \text{Eq. 1}$$

where EF_i is the emission factor of species i in terms of gram effluent per kilogram fuel , f_c is the fraction of carbon in the fuel, ER_i is the mass emission ratio of species i, ΔCO_2 is the background-corrected mass concentration of CO_2, ΣCj is the background corrected mass concentration of carbon in major carbon emissions species j. The majority of the carbon emissions will be emitted as carbon dioxide. With this assumption, carbon dioxide is the only carbon-containing compound that is required to be measured at each measurement location.

Field data will be transferred from the data loggers to external hard drives via a laptop computer with a USB port. Electronic data and pictures will be posted in the folder L:\Lab\NRML_Public\GullettResearchUpdates\ on the EPA network share drive upon return from the field or as they are generated or received.

Laboratory reports received from Chester LabNet for PM_{10} concentrations will be validated by Dennis Tabor to ensure that the data reported is supported by appropriate quality control checks identified in the methods. Mr. Tabor will tabulate laboratory results and provide final data to Dr. Gullett for emission factor calculations.

7 Quality Assessment and Oversight

This project is QA Category B and does not require planned technical systems and performance evaluation audits. However, should deficiencies be identified by any of the key individuals responsible, the EPA PI will discuss the problem and corrective actions to be taken for subsequent sampling or analyses.

8 Environmental and Safety

A “Safety, Health, and Environmental Management Protocol for Field Activities” form including National Environmental Policy Act (NEPA) requirements, specific to environmental and personnel health and safety, has been reviewed and approved by EPA’s Safety Office and ORD Management.

Tall Timber personnel shall be responsible for any operation involving fire starting/suppression.

Accident/Incident Report: EPA shall report immediately any major accident/incident (including fire) resulting in any one or more of the following: causing one or more fatalities or one or more disabling injuries; damage of Government property exceeding $10,000; affecting program planning or production schedules; degrading the safety of equipment under initiative, such as personnel injury or property damage may be involved; identifying a potential hazard requiring corrective action. EPA shall prepare the report (DI-SAFT-81563) for each incident.

9 Deliverables and Reporting

ORD will supply emission factors to USGS through a draft report or journal article, as determined by the USGS project lead, Todd Hoefen.

10 References

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