

**1.0 Title Page**

**Standard Operating Procedures**

**Thermo Environmental Instruments Model 48C Trace Level  
Gas Filter Correlation Carbon Monoxide Analyzer**

NOTICE: This Standard Operating Procedure is written for use with the above named analyzer or system at the EPA/OAQPS/AAMG Burdens Creek ambient air monitoring site located in Research Triangle Park, North Carolina.

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### **3.0 Introduction**

This standard operating procedure (SOP) document describes the procedures used by members of the Ambient Air Monitoring Group (AAMG) to operate a continuous carbon monoxide (CO) analyzer at the Environmental Protection Agency, Office of Air Quality Planning and Standards (EPA OAQPS) Burdens Creek monitoring site located in Research Triangle Park, North Carolina. The procedures given in this SOP are to be used in conjunction with the monitoring site's Quality Assurance Project Plan (QAPP), the latest information published in the Code of Federal Regulations, and the Operator's manual for the Thermo Environmental Instruments Model 48C-Trace Level (TEI 48C TLE) CO analyzer .

#### **3.1 Scope**

For trace level measurement of CO the analyzer must have a sensitive detector. The TEI model 48C TLE is a state-of-the-science instrument for the determination of trace levels of CO by non-dispersive infrared (NDIR) spectrophotometry using gas filter correlation (GFC). This SOP will describe the monitor and its operation.

#### **3.2 Method Description**

The analytical principle is based on absorption of IR light by the CO molecule. NDIR-GFC analyzers operate on the principle that CO has a sufficiently characteristic IR absorption spectrum such that the absorption of IR by the CO molecule can be used as a measure of CO concentration in the presence of other gases. CO absorbs IR maximally at 2.3 and 4.6  $\mu\text{m}$ . Since NDIR is a spectrophotometric method, it is based upon the Beer-Lambert law. The degree of infrared radiation reduction depends on the length of the sample cell, the absorption coefficient, and CO concentration introduced into the sample cell, as expressed by the Beer-Lambert law shown below:

$$T = I/I_0 = e^{(-axC)} \quad (\text{equation 1})$$

where:

T = Transmittance of light through the gas to the detector  
I = light intensity after absorption by CO  
I<sub>0</sub> = light intensity at zero CO concentration  
a = specific CO molar absorption coefficient  
x = path length, and  
C = CO concentration

For GFC, there is only one sample cell. This cell acts as the sample and reference cell. The broad band of IR radiation is emitted from an IR source. The IR light passes through a very narrow band pass filter which screens out most wavelengths and allows only the light that CO absorbs to enter the sample cell. The GFC analyzer has a chopper wheel with cells containing two pure gases: nitrogen (N<sub>2</sub>) and CO. As the chopper wheel rotates and allows the IR energy to enter “CO side” of the wheel, all IR energy that could be absorbed by CO in the sample stream is absorbed by the CO in the wheel. This technique effectively “scrubs out” any light that could possibly be attenuated. The single detector records the light intensity (I<sub>0</sub>). As the wheel spins, the “N<sub>2</sub> side” of the wheel enters the IR energy beam. This side of the wheel allows all IR light to pass through the wheel and be absorbed by any CO that might be in the sample gas. This light level is CO sensitive (I). The detector records the attenuation of this light, compares the two light levels (I/I<sub>0</sub>) and sends a signal to the electrometer board that calculates the concentration. The voltage is related to the CO concentration according to the Beer-Lambert law in equation 1 shown above. In this way the TEI 48C TLE can measure CO continuously. The 48C TLE version has four distinct features that allow it to measure CO at ppb levels:

- Xrequired sample stream dried using permeation dryer;
- Xanalyzer baseline determined and corrected using heated Carolite catalytic converter;
- Xfrequent auto-zero, at a minimum once per hour, through the catalytic converter;
- Xan ultra-sensitive or “hot” detector.

### 3.3 Interferences

Interferences are physical or chemical entities that cause measurements to be higher (positive) or lower (negative) than they would be without the entity. Studies have shown conclusively that NDIR analyzers have interference from water vapor. Water absorbs very strongly across several bands of IR spectra. Water vapor interference occurs because in the IR region it absorbs of light at 3.1, 5.0 -5.5 and 7.1 -10.0  $\mu\text{m}$ . As a result, there is a quenching effect on the absorption of infrared light by CO. The TEI 48C TLE is

equipped with a permeation dryer, which effectively removes all water and water vapor. No maintenance is required on the dryer.

Carbon dioxide (CO<sub>2</sub>) absorbs in the IR spectrum at wavelengths of 2.7, 5.2, and 8.0 to 12.0  $\mu\text{m}$ . This is very close to the regions that CO absorbs within as well. Because atmospheric CO<sub>2</sub> is much higher in concentration than CO, this UV spectral range must be avoided. To prevent light in this spectral region, the TEI 48C TLE analyzer has a band pass filter that blocks these wavelengths.

In order to measure in the ppb range, it is important for the detector to be operated at a very stable temperature. To obtain a stable baseline, the temperature of the detector and optical bench must be maintained within  $\pm 1.0$  degree Celsius ( $^{\circ}\text{C}$ ) of the set value.

### **3.4 Data Quality Objectives**

The Burdens Creek site provides the EPA/OAQPS/AAMG with the ability to test new monitoring and data acquisition/data transfer technologies and to train monitoring organizations in these technologies. Data are gathered at the Burdens Creek site in a manner similar to state, local, and tribal monitoring organizations in order to assist or guide others and to test two data acquisition systems' ability to transfer data to information management programs like AIRNow and the AQS system. Carbon monoxide will be measured year-round on a range setting of 0 to 5 ppm (0 to 5000 ppb) and reported at a minimum frequency of one-hour averages.

The decision rule for determining the quality of the Burdens Creek CO data is not based on comparison to the National Ambient Air Quality Standard (NAAQS), but rather on whether or not the data meet the measurement quality objectives of precision and bias. Precision and bias will be estimated from the quality control (QC) zero, span, and precision checks that are made automatically by the calibration system or manually by the site operator at least every two weeks.

The Burdens Creek site will use the data quality objectives (DQOs) developed by EPA for determining whether or not a particular monitoring system is performing properly and what corrective actions might be needed. The goal for acceptable measurement uncertainty for CO measurements is defined for precision as an upper 90 percent confidence limit for the coefficient variation (CV) of 15 percent, for bias as an upper 95 percent confidence limit for the absolute bias of 10 percent, and a minimum data completeness of 90 percent. Thus, the Burdens Creek site data set will be assumed to have met the DQO if the measurement quality objectives (MQO) of 15% or better for precision and 10% or better for bias are consistently met over the months and years of site operation. A tabular presentation of the MQOs for CO is given in Table 2 of Section 8.

### **3.5 Personnel Qualifications and Training**

The person(s) assigned to operate the 48C TLE CO analyzer should receive classroom instructions, hands-on sampler training, and safety briefings from an experienced site operator. The desired qualifications for an operator include: a good understanding of basic chemistry and electronics; understanding of digital circuitry; coursework and/or experience in ambient air data processing and validation.

### **4.0 Health and Safety Procedures**

CO is a poisonous gas. The CO, or any other calibration span gas, should be vented to the atmosphere rather than into the shelter or other sampling area. If this is impossible, limit operator exposure to CO by getting fresh air every 5 to 10 minutes. The operator must leave the area immediately if he experiences light headedness, headache or dizziness.

#### **4.1 Preventing Personal Injury**

To prevent personal injury, the following warnings and cautions must be observed when operating the 48C TLE.

1. Always unplug the analyzer when servicing or replacing parts.
2. Always use a third ground wire on all instruments.
3. The IR source is a filament resistor that has an electrical current running through it and can become very hot. When troubleshooting, if the IR source is the suspected cause of the problem, allow the source to cool sufficiently.
4. If it is mandatory to work inside an analyzer while it is in operation, use extreme caution to avoid contact with high voltages. The analyzer has a 110-Volt Alternating Current (VAC) power supply. Refer to the manufacturer's instruction manual and know the precise locations of the VAC components before working on the instrument.
5. Avoid electrical contact with jewelry. Remove rings, watches, bracelets, and necklaces to prevent electrical burns.

#### **4.2 Cautions**

To prevent damage to the analyzer, the following precautions should be taken:

1. In the event that it is necessary to clean the optical bench, be careful to avoid damaging the interior of the sample chamber. In addition, some GFC



instruments have a series of mirrors that deflect the light in order to increase the path length. The mirrors are aligned at the factory. If the mirrors become misaligned, the IR light beam will not be directed to the detector. Use extreme caution when cleaning or servicing the sample chamber(s). In addition, the mirrors are very fragile. Avoid dropping the instrument. This may damage, misalign or crack the mirrors and cause expensive repairs.

2. Keep the interior of the analyzer clean.
3. Inspect the system regularly for structural integrity.
4. To prevent major problems with leaks, make sure that all sampling lines are reconnected after required checks and before leaving the site.
5. Inspect tubing for cracks and leaks. The permeation dryer may rest upon parts that vibrate, such as the air pump. Check the areas of the permeation dryer where they come into contact with other parts.
6. It is recommended that the analyzer be leak checked after replacement of any pneumatic parts.
7. If cylinders are used in tandem with mass flow control (MFC) calibrators, use and transport of cylinders are a major concern. Gas cylinders can sometimes contain pressures as high as 2000 pounds per square inch. Handling of cylinders must be done in a safe manner. If a cylinder is accidentally dropped and the valve breaks off, the cylinder can become explosive or a projectile.
8. Transportation of cylinders is regulated by the Department of Transportation (DOT). It is strongly recommended that all agencies contact the DOT or Highway Patrol to learn the most recent regulations concerning transport of cylinders.
9. CO is a highly poisonous gas. Long term exposure can cause problems with motor coordination and mental acuity. It is strongly recommended that all agencies have material safety data sheets (MSDS) at all locations where CO cylinders are stored or used. MSDS can be obtained from the DOT or from your vendor.
10. It is possible (and practical) to blend other compounds with CO. If this is the case, it is recommended that MSDS for all compounds be made available to all staff that use and handle the cylinders.

11. Shipping of cylinders is governed by the DOT. Contact the DOT or your local courier about the proper procedures and materials needed to ship high-pressure cylinders.

## **5.0 Siting and Sampling**

### **5.1 Site Characteristics**

The Burdens Creek site is located within 0.5 mile of the EPA/OAQPS facility in Research Triangle Park, NC. The site is adjacent to Alexander Drive and N.C. Route 147 and is intended to represent a neighborhood scale location. The site conforms to many of the network and siting requirements for air monitoring as stated in Title 40 of the Code of Federal Regulations (CFR), Part 58, Appendix D (40 CFR Part 58, Appendix D). While the site is like an NCore site in many respects, it is not a designated NCore site.

### **5.2 Air Sample Routing**

The CO sample inlet probe is an inverted glass funnel, located on the roof of the shelter, approximately 5 meters above ground level. The funnel inlet is greater than 1 meter vertically and horizontally away from any supporting structures; the drip-line of the nearest tree is greater than 20 meters from the probe inlet. Sampling for trace level CO is performed by using a vacuum pump to continuously draw ambient air from the station's glass sampling manifold directly into the analyzer. The air inlet probe and sampling manifold for CO monitoring are designed so that residence time in the assembly is less than 20 seconds.

### **5.3 Equipment and Supplies**

**TEI 48C TLE CO Analyzer:** The Burdens Creek site uses the TEI 48C TLE CO analyzer. For this site, its range is set to 0 to 5.0 ppm (0 to 5000 ppb). All fittings and tubing associated with the delivery of ambient air CO samples, or calibration and QC gases, are composed of Teflon or glass. The features of the analyzer are fully described in the operator's manual. The three main components of the 48C TLE are the:

Pneumatic System: Consists of sample inlet line, particulate filter, filter holder, permeation dryer, reaction chamber, flow meter, and pump, all used to bring ambient air samples to the analyzer inlet.

Analytical System: This portion of the instrument consists of the IR source, the correlation wheel, motor, mirrors, detector and band pass filter.

Electronic Hardware: The part of the analyzer that generally requires little or no maintenance. The brain of the 48C series is the CPU. It monitors and regulates

motor speed, temperatures, flows and pressure. It also monitors and stores diagnostic information. If the 48C TLE is operated above the manufacturer's recommended temperature limit, individual integrated chips can fail and cause problems with data storage or retrieval.

**Instrument Shelter:** A shelter is required to protect the analyzer from precipitation and adverse weather conditions, maintain operating temperature within a  $\pm 2$  °C range within the analyzer's temperature range requirements, and provide security and electrical power. The acceptable shelter temperature range is 20-30 °C. An ideal range of temperature control would be  $25 \pm 1$  °C.

**Calibration System:** The Burdens Creek site uses a model 9100 Environics® calibration system to create concentrations of CO by diluting the contents of a NIST traceable compressed gas cylinder. For details on the operation of the calibration system, refer to the Environic Operator's Manual and to the SOP "*Standard Operating Procedures, Environics Series 9100, Computerized Ambient Monitoring Calibrations System*". The compress gas cylinders at the site are multi-blend mixture of the target analytes with a nitrogen base. The zero air at the site is produced by pumping room air through an Advanced Pollution Instruments (API) model 701 zero air module. For removal of CO<sub>2</sub> the air is also passed through a Purafil/charcoal scrubber. All gas must be delivered to the instrument at atmospheric pressure.

**DAS:** The ENVIDAS for Windows (EFW) data system is the primary digital data acquisition system for the Burdens Creek site. The ENVIDAS system uses non-proprietary desktop or industrial personal computer hardware to run flexible, Windows-based data acquisition software. Data can be averaged, archived, displayed, and reported in various formats, including display of data as an "electronic strip chart." ENVIDAS is designed to communicate with and control a variety of precursor gas analyzers and dynamic dilution calibrators. The ESC 8832 data logger is used as the backup system for recording analog data at the Burdens Creek station. For more details, refer to the individual ENVIDAS or ESC 8832 operator's manual and to the Burdens Creek SOP for DAS operations.

**Wiring, Tubing and Fittings:** Teflon™ and borosilicate glass are inert materials that should be used exclusively throughout the ambient air intake system. It is recommended that Polytetrafluoroethylene (PTFE) or Fluoroethylpropylene (FEP) Teflon™ tubing be used. PTFE or FEP Teflon is the best choice for the connection between the intake manifold and the 48C TLE bulkhead fitting. Examine the tubing and discard if particulate matter has collected on the tube's interior. All fittings and ferrules should be made of Teflon™ or stainless steel. Connection wiring to the DAS should be shielded two-strand wire or RS-232 cables for digital connections.

**Reagents and Standard:** The TEI 48C TLE does not require any reagents since the instrument uses photometry to analyze for CO. All gas calibration and quality

control concentrations for the CO method are obtained by dynamic dilution of gas from cylinders whose contents must be traceable to NIST Standard Reference Material (SRM) gases via EPA Protocol procedures.

**Spare Parts and Incidental Supplies:** See Chapter 5 (Preventive Maintenance) and Chapter 7 (Servicing) in the TEI 48C TLE operating manual for specific maintenance and replacement requirements.

## 6.0 48C TLE Analyzer Installation, Operation, Calibration, and Maintenance

### 6.1 Overview

The TEI 48C TLE instrument has a front panel screen with digital display. The screen and a set of push button operating switches located below it allow the user to check functions, switch operating parameters, adjust zero and span, and read warnings messages.

**Caution:** It is extremely important that the users familiarize themselves with the menus available. Inadvertently changing parameters within the analyzer can damage the instrument and possibly invalidate data as well. Please reference the TEI 48C TLE owner's manual and read it carefully before adjusting any parameters that are set by the factory.

Section 2.0 of the operator's manual must be consulted to understand or carry out the following initial setup procedures, including:

- X How to unpack and inspect the exterior and interior of the analyzer,
- X Setup procedures for making pneumatic connections for sample and calibration gases, and
- X How to make electrical connections for: output, status outputs, control inputs, serial ports, and other features.

Refer to Figure 1 for an illustration of the analyzer's front panel and to Figure 2 for an illustration of the pneumatic connections.



Figure 1. Front Panel of the TEI 48C

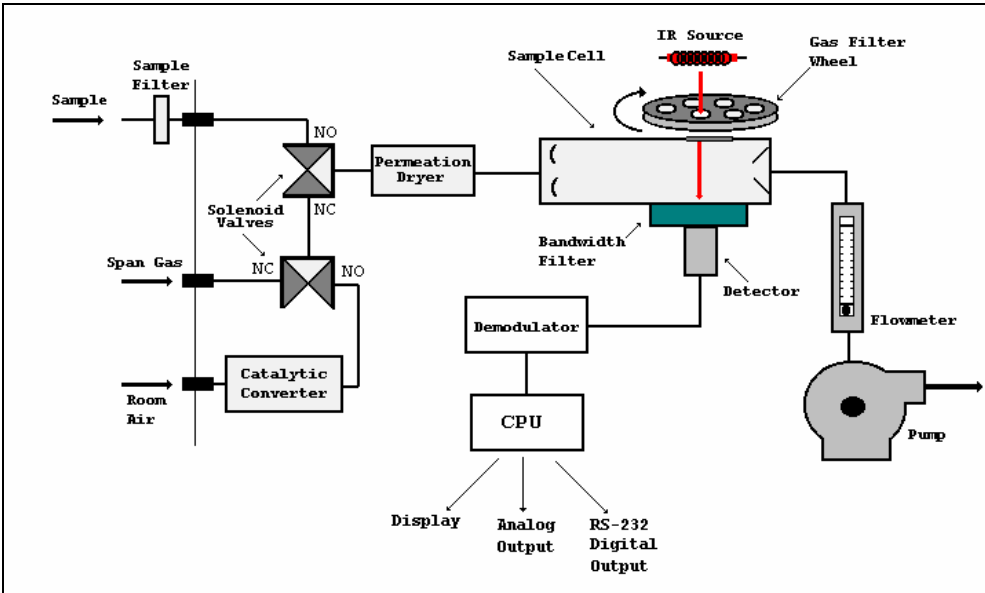


Figure 2. Pneumatic Diagram for TEI Model 48C TLE CO Analyzer

The 48C TLE instrument operates in the following fashion:

1. The sample stream first passes through a sample filter, which removes particles and thus preventing their build-up on the mirror and sample chamber and attenuation of the IR beam.
2. In sample mode, ambient air is pulled in through the particulate filter and goes into the rear bulkhead sample port. The first solenoid encountered is in its “Normally Open” (NO) mode. The ambient air flows through the solenoid to the permeation dryer, which removes the moisture and water from the air stream.
3. The sample then enters the sample cell. A major difference between a non-trace level and a trace level ambient air analyzer is the detector construction. The trace level instrument has a detector that is more sensitive to the light emitted and absorbed in the sample cell. This detector must be more sensitive because the degree of attenuation by the low concentrations of CO gas in the sample stream is much lower and must be detected to give reliable low concentration values. Temperature control of the sample cell is also critical. The sample cell and detector must be maintained at a constant temperature in order for the detector to keep a stable background. Fluctuations of more than 1°C can cause the baseline to drift, giving false readings at low levels.

4. The detector sends the signal to the demodulator which interprets the signal. The demodulator sends a digital value to the Central Processor Unit (CPU).
5. At the end of the hour, the CPU sends a voltage signal to the first solenoid and switches it to the “Normally Closed” (NC) position. This allows room air to be drawn into the instrument and to pass through the catalytic converter. The catalytic converter uses a Carolite bed heated to 50°Centigrade to convert all CO to CO<sub>2</sub> ( $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$ ). This effectively scrubs all CO from the sample stream. The “CO-free” air flows through the sample cell and the CPU interprets the signal from the demodulator as the “background” or “baseline” value. The baseline is then adjusted at that time. The baseline adjustment takes 10 minutes.
6. The CPU then switches the first solenoid to its “Normally Open” (NO) position and ambient air is again drawn into the analyzer.

## 6.2 Startup

### 6.2.1 Analyzer setup

After the analyzer is removed from the shipping container and placed on a sturdy bench top or in an instrument rack, remove the outer cover and any packing material from the internal compartment. Next, the internal components should be inspected for damage. After reinstallation of the instrument cover, sample lines are connected to the bulkhead on the rear panel.

### 6.2.2 Tubing and gas delivery

All tubing should be constructed of Teflon™ with an outside diameter (OD) of ¼ inch and a minimum inside diameter (ID) of ⅛ inch. The length of the tubing should be less than 10 feet. For delivery of gases at atmospheric pressure it might be necessary to use an atmospheric bypass plumbing arrangement or to attach the analyzer inlet line to a ambient air intake manifold that is vented to the atmosphere. An exhaust line of the same dimensions as previously noted is connected to a suitable vent. For proper analyzer operation, it is essential that no tubing be restricted or kinked.

### 6.2.3 Electrical connections

The 48C TLE is supplied with a three-wire grounding cord. Under no circumstances should this grounding system be defeated. The instrument must be plugged into an outlet of the appropriate voltage and frequency. For these specifications, see page 1-3 in Chapter 1 of the operator’s manual.

## 6.3 Operation and Range Setting

Refer to Chapter 3 of the operator's manual for detailed descriptions and views of the pushbuttons, menus and displays. When the power to the instrument is turned on, the exhaust fan and the front panel display will come on. Next, the central processing unit (CPU) will boot the system and load the firmware. While an overnight warm-up is recommended, a minimum 30-minute warm-up time should occur before proceeding.

### 6.3.1 Display

The front panel of the instrument has a 4 line by 20 character alphanumeric display that shows the sample concentration, instrument parameters, instrument controls and help/warning messages. The pushbuttons on the front panel are used to access the menu driven software. Some menus contain more items that can be displayed at one time. If this is the case, the ↑ and ↓ pushbuttons are used to move the cursor through the available choices.

### 6.3.2 Run Screen

Once the instrument loads the firmware, the display will read the CO concentration as "CO PPM XX.XX", and show the time and the word "REMOTE" below this. The instrument is now at the "RUN" menu and should always be left in this mode when it is collecting ambient data. Press the "Menu" button to access the main menu.

### 6.3.3 Range Displays

Use the down arrow to move to the "Range" menu. Press "Enter." The "Range" menu contains the gas units (ppm), CO ranges, or the custom ranges. In the upper right corner of the display, the word "SINGLE", "DUAL", or "AUTO" is displayed to indicate the active mode. The default range is the "SINGLE" mode. Refer to page 3-11 of the operator's manual for the beginning of the discussion of setting the limits for the CO range and custom ranges.

## 6.4 Diagnostic Checks

Diagnostic checks to determine whether the 48C TLE is working properly should be performed every time the site is visited—even though the purpose of the visit may be to work with another instrument. The diagnostic checks for the 48C TLE can be conducted manually or by using the computer software. Figure 3 shows a menu tree for the diagnostic checks that was taken from the manual for a similar instrument, the TEI 48 C-TL.

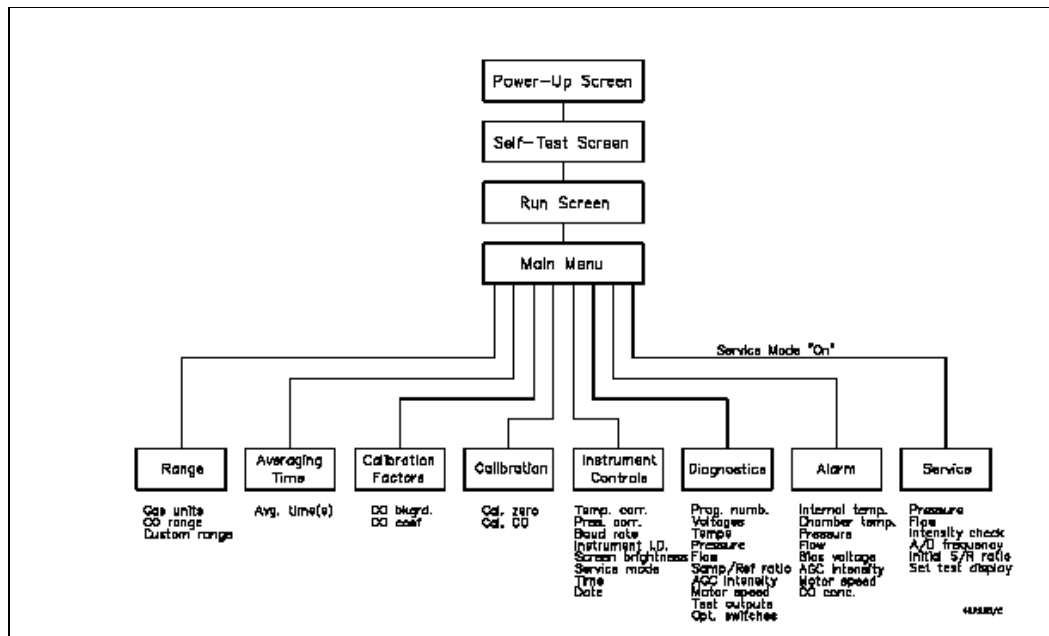


Figure 3. Menu Tree for Diagnostic Checks

By pressing the “menu” button and following the menu tree, the desired location can be easily reached. Note that because the TEI 48C TLE has set upper and lower ranges for some of these diagnostic checks, the operator’s manual should be referenced for working with these ranges. Use the following instructions to manually perform the diagnostic checks.

1. While in the “Run” menu, press the “Menu” button. This will put you into the main menu.
2. From the main menu use the ↑ and ↓ pushbuttons move the cursor down so that the arrow is next to “Diagnostics” selection. Press “Enter.”
3. In the “Diagnostics Menu”, toggle the arrow using the ↑ and ↓ pushbuttons to align the arrow to the diagnostic to be evaluated. To view the results, press “Enter” record the information on a diagnostic data form. Figure 4 is the diagnostics data form used at the Burdens Creek site to record the results. The top portion of the form is used to record the diagnostic checks. The latter section is used to record the results of the QC checks discussed in Section 7 of this SOP.



**Environmental Protection Agency  
Quality Control and Maintenance Records  
TEI 48C TLE CO Analyzer**

Site Name/Location \_\_\_\_\_ Date \_\_\_\_\_ Time \_\_\_\_\_  
 Technician \_\_\_\_\_ Instrument ID# \_\_\_\_\_ Date of Last Calibration \_\_\_\_\_

TEI Diagnostics	Actual Reading	Acceptance Criteria	Acceptable?
Range		0-5.000 ppm	
Averaging Time		10-300 seconds	
CO Background		0-12	
CO Span Coefficient		0.900-1.100	
Basic Voltage		-105 to -115V	
Power (+5/+15/-15/Battery)		±0.1V, >3.0V	
Internal Temperature		8-47 °C	
Chamber Temperature		48-52 °C	
Chamber Pressure		650-760 mm Hg	
Sample Flow		0.35-1.0 L/min	
S/R Ratio		1.14-1.18	
AGC Intensity		150,000-250,000 Hz	
Motor Speed		100%	
Change Particle Filter	Y N	Auto Zero Freq (Hrs)	

**Quality Control Results**

Calibrator Type/SN \_\_\_\_\_ Certification Date \_\_\_\_\_ Expiration Date \_\_\_\_\_  
 STD#, PPM, PSIG \_\_\_\_\_ Certification Date \_\_\_\_\_ Expiration Date \_\_\_\_\_

Point #	Expected CO, ppb	Actual Calibrator, ppb (Y)	Observed 1-min. average, ppbEFW (X)	Observed 1-minute average, ppb, ESC	% Deviation EFW	% Deviation ESC
1						
2						
3						
4						
5						
6						

Unadjusted 3-point Calibration \_\_\_\_\_ Unadjusted M-P Calibration \_\_\_\_\_ Adjusted M-P Calibration \_\_\_\_\_  
 Zero pt ± 20 ppb Y N Precision Point ± 15% of expected value Y N All calibration points ± 5% Y N  
 EFW Regression Criteria: XY (0.9800 < M < 1.0200) \_\_\_\_\_ (-40.00 < B < 40.00) \_\_\_\_\_ R<sup>2</sup> (> .9950) \_\_\_\_\_

Comments: \_\_\_\_\_

**Figure 4. Data Form for Diagnostic Checks and Quality Control Checks: TEI 48C TLE CO Analyzer**

4. Press “Menu” and then “RUN” to return the analyzer to the main menu. Once the diagnostic checks have been established and recorded for the 48C TLE, it is time to check the calibration of the analyzer and, if required or scheduled, to calibrate the instrument.

## 6.5 Initial and Periodic Multipoint Calibration

The next step is to conduct an initial or periodic adjusted multipoint (MP) calibration of the 48C TLE analyzer. Adjusted MP calibrations are conducted every 90 days. Before beginning the calibration process, ensure that both the ENVIDAS FW DAS and the ESC 8832 DAS are set “off line.” This section of the SOP will describe how to compare and adjust the digital response of the 48C TLE to various calculated concentrations of CO. The calibration points are generated by diluting a higher concentration of CO from a NIST-traceable calibration gas to a target concentration. The recommended ranges for the MP calibration points are detailed in Table 1. As each calibration point is generated, the responses shown by the DAS should be compared to the calculated value. If the difference exceeds +/-10%, the instrument’s response should be adjusted as detailed in the following sections.

### 6.5.1 Pre-calibration checks

Prior to conducting any calibrations, it is important to ensure that the analyzer is properly warmed up and leak-free. To ensure proper operation, the maintenance procedures described in Section 10 of this SOP should be reviewed and conducted as necessary.

### 6.5.2 Adjustment to Zero Air

The instrument response to zero air is adjusted by performing the following steps:

1. For a minimum of 15 minutes, allow the instrument to sample zero air from a manifold that is at atmospheric pressure.
2. Before any adjustments to the instrument can be made, the instrument must be put into “LOCAL” mode. This is done by pressing “ENTER” while the instrument is displaying the “RUN” screen. Pressing “ENTER” while in the “RUN” mode enables the operator to toggle between “REMOTE” and “LOCAL” modes.
3. Bring up the main menu by pressing the “MENU” button on the front panel of the instrument. From the main menu, use the ↑ or ↓ button to move the cursor to align with “Calibration” on the screen; press “ENTER”.

4. Continue to press the arrow button(s) until the cursor is aligned with the “Calibrate Zero” position on the screen; press “ENTER.” The bottom of the display will flash the message “SAVING PARAMETER(S),” and the CO reading will be added to the background correction.
5. Press “MENU” to return to the “Calibration” sub-menu. The baseline is now adjusted to reflect the instrument’s response to zero air.

**Table 1. Operating Parameters for the TEI 48C TLE CO Analyzer**

Item	Range	Comments
Units	Parts per million (ppm)	Recommended
Full scale range	0 to 5.000 ppm	Suggested range. Reduce to 1.000 ppm if rural site.
Compressed gas cylinder	200-250 ppm	NIST traceable EPA Protocol #1 cylinder.
Calibration point:		
a. zero	0-0.010 ppm	There are a number of commercially available vendors of zero air sources.
b. Level 1 span	4.000-5.000 ppm	NIST traceable EPA Protocol #1 cylinder with concentration between 200-250 ppm. Recommended gas flow range 75-90 cc/min. Zero air flow 4.80-5.00 L/min.
c. Midpoint span	2.000-2.500 ppm	NIST traceable EPA Protocol #1 cylinder with concentration between 200-250 ppm. Recommended gas flow range 75-90 cc/min. Zero air flow 8.000-10.00 L/min.
d. Precision point	0.250-0.500 ppm	NIST traceable EPA Protocol #1 cylinder with concentration between 200-250 ppm. Recommended gas flow range 20-35 cc/min. Zero air flow 18.00-20.00 L/min.

### 6.5.3 Adjustment to Calibration Gas (Span point)

The instrument response to the NIST traceable calibration gas is adjusted by performing the following steps:

NOTE: Do not perform calibrations during the time that the analyzer is undergoing the automated internal auto-zero function.

1. Adjust the Environics® 9100 calibration unit to generate a known concentration of CO. Allow the instrument to sample calibration gas from a manifold that is at near atmospheric pressure for a minimum of 15 minutes.

2. As instructed earlier, before any adjustments to the instrument can be made, the instrument must be put into "LOCAL" mode. Pressing "ENTER" while in the "RUN" mode enables the operator to toggle between "REMOTE" and "LOCAL" modes.
3. On the front panel of the 48C TLE press the "Menu" button. This will bring up the main menu. Use the  $\uparrow$  or  $\downarrow$  button to move the cursor until it aligns with the "Calibration" selection and then press "Enter."
4. This next screen is the "Calibration" screen. In this screen press the  $\downarrow$   $\uparrow$  buttons until the cursor aligns with the "Calibrate CO" selection and then press "Enter."
5. The first line of the display shows the current CO concentration reading. The second line shows the instrument range and the third line states, "SET TO..... XX.XX." The next line shows " $\downarrow$   $\uparrow$  INC/DEC." The cursor should be under one of the digits in the third line. Use the " $\downarrow$   $\uparrow$   $\rightarrow$   $\leftarrow$ " buttons on the front panel to enter in the concentration that is being generated by the calibration system. Press "Enter."
6. Press "Menu" and then press "Run." This will adjust the response of the instrument to the calibration gas concentration. The zero and span of the instrument is now set.

#### 6.5.4 Multipoint Calibrations

Use the calibration system instructions given in section 7.4 to continue generating the desired concentrations that fall within the calibration ranges shown in Table 1. Record the data in the lower section of the data form shown in Figure 4. Generate a linear regression by plotting the analyzer response against the calculated concentration. Observe that the calculated values for the regression parameters do not exceed the regressions limits: slope (M),  $0.9800 < M < 1.0200$ ; intercept (B),  $-40.00 < B < 40.00$ , and  $R^2 > 0.9950$ .

##### 6.5.4.1 Frequency of calibrations

The operating manual recommends that a multipoint calibration be performed: every three months; any time any major disassembly or servicing of components is performed; and any time that zero or span checks give results outside of the performance criteria.

##### 6.5.4.2 Periodic Quality Control Checks

For the Burdens Creek site, periodic zero, span, and precision checks may be conducted during a routine site visit by the operator responsible for the CO monitoring operations. The details for conducting these checks are provided in Section 7.

#### 6.5.5 Auto-Zero Function

The TEI 48C TLE analyzer is equipped with an automatic zero check function. In the default setting, this auto-zero function will occur at the end of the hour. The auto-zero function can be modified from once per hour to any increment up to once per day. It is important that the operator be aware of the auto-zero function in that no calibrations or QC procedures should be conducted at or near the scheduled time for the auto-zero.

When the auto-zero function is activated, the 48C TLE analog output will be at or close to zero, since the detector is sampling air with the CO “scrubbed out,” and the display will show “ZERO.” If the auto-zero data is recorded, the operator must flag the data in the DAS.

### 7.0 Routine Site Visits

Visits to the Burdens Creek site to check the CO analyzer and other equipment are made biweekly, in the mornings. Pollutant monitors for oxides of nitrogen, ozone, and sulfur dioxide, as well as other site systems are usually checked on a routine schedule. Listed below are site visit procedures that pertain to the TEI 48C TLE CO analyzer and the supporting monitoring equipment. To be able to carry out these checks it is necessary that the site visitor be fully trained and familiar with operator’s manuals for all equipment and with their specific SOPs. Any findings indicating the need for analyzer maintenance or recalibration must be recorded in the site logbook and reported to the site supervisor.

#### 7.1. Inspect Shelter Condition and Status

When visiting the site by vehicle, park the vehicle well away from the ambient air sampling inlet to avoid contamination from exhaust emissions. Before entering the Burdens Creek shelter, conduct a visual survey of the site; checking the external sampling lines for cleanliness and integrity; check the meteorological tower components, and search for any evidence of damage or vandalism to the shelter and sample inlets.

#### 7.2 Operational Requirements for Entering the Station

When entering the station, observe the operational requirements posted on the far wall of the monitoring station.

1. Sign in the site logbook with your name, the time and date, the purpose of the visit, etc.

2. Check the room temperature displayed on the digital temperature sensor located on the far side of the station. Record the reading in the logbook. If the temperature is markedly different from the usually 24 to 26 °C range or is outside the 20 to 30°C limits, record these observations and report the findings to the station supervisor.

Note: Cold conditions inside the shelter can cause condensation of water vapor inside the glass sampling manifold and inside Teflon sampling tubing. If visual observation shows water condensation, notify the site supervisor promptly and take action to reset the shelter temperature, remove the condensed water, and conduct analyzer calibration checks.

3. Before running the diagnostic check on the CO analyzer, observe the ENVIDAS FW display to verify that all systems in the station are operating properly. Conduct a visual check of each analyzer's front panel display for reasonableness of the pollutant concentrations and for indications of FAULT or other messages. Make a notation in the station logbook that the checks were made and write down any FAULT or message indicating out-of-tolerance conditions for any analyzer.
4. Determine and make a notation of the type of calibration to be executed. The unadjusted 3-point calibration is conducted every two weeks. The adjusted multipoint calibration is conducted every 90 days.

### 7.3 Data Acquisition Systems

Parallel data acquisition systems are used for data collection at the Burdens Creek site. Use the keypad for each system to link to the data logger. On the ENVIDAS FW (EFW) use the keypad to activate the channel selection screen (Figure 5). The screen will promptly display all the parameters being monitored by the EFW system. The screen updates every 5 seconds. To view the past day's data, click on the icon for the "Reporter" program to bring up the data. Compare the instantaneous values displayed by the EFW to those displayed on the front panel of the 48C TLE. The values should be identical.

The screenshot shows a window titled "Dynamic Tabular" with the subtitle "EPA0AQPS1". It contains a table with 27 rows and 6 columns. The columns are: Channel, Input Signal, Instantaneous, Last 5Min AVG., Last 1Min AVG., and Last 60Min AVG. The data is as follows:

Channel	Input Signal	Instantaneous	Last 5Min AVG.	Last 1Min AVG.	Last 60Min AVG.
01 - CO - TEI [PPB]		207.000	207	207	231
02 - SO2-TEI [PPB]		6.104	0.10	0.06	0.09
03 - HO-AOD [PPB]	HoData	HoData	HoData	HoData	HoData
04 - HOy-AOD [PPB]	HoData	HoData	HoData	HoData	HoData
05 - HO2-AOD [PPB]	HoData	HoData	HoData	HoData	HoData
06 - SITEMP [DEGC]		0.239	23.9	23.4	23.3
07 - CO - API [PPB]		232.000	232	210	241
08 - O3-API [PPB]	RS232_0.000	RS232_0.0	21.2	22.2	9.6
09 - WS Prop 10M [m/s]		1.000	1.5	1.6	2.3
10 - WD Vane 10M [deg]		39.000	39.0	1.3	23.5
11 - TEMP 2M [dege]		21.900	22.9	22.7	22.8
12 - RH [%]		93.000	93	95	94
13 - Precip. [MM]		0.000	0.0	0.0	0.0
14 - HO-API [PPB]		2.557	2.56	1.62	2.67
15 - HOy-API [PPB]		13.420	13.42	14.35	13.84
16 - HO2-HO2-API [PPB]		10.863	10.86	9.73	11.17
17 - Manifold Flow [ft Min]		0.905	362.00	367.23	360.36
18 - Solar Radiation [WM2]		0.028	454	342	474
19 - WS Ultra 10M [m/s]		0.171	1.71	1.65	2.08
20 - WD Ultra 10M [degTH]		3.500	26.6	347.0	12.4
21 - Elev Ultra 10M [deg]		2.779	6.7	5.5	-8.8
22 - CO-DIFF [ppb]	HoData		25	3	11
23 - SO2-API [ppb]		0.240	0.24	0.15	0.24
24 - SO2-DIFF [PPB]	HoData		0.14	0.08	0.15
25 - HOy-Flow [l/m]	HoData	HoData	HoData	HoData	HoData
26 - HOy Conv Temp [degrees C]	HoData	HoData	HoData	HoData	HoData
27 - HO2 - AOD [ppb]	HoData	invalid_0.00	invalid_0.00	invalid_0.00	invalid_0.00

Figure 5. ENVIDAS FW Dynamic Tabular Channel Display

When conducting calibration checks, the data acquisition systems must be set “off line.” Go to the EFW configuration menu, enter the username “a” (no password required), locate the channel associated with the instrument, change the online status to ”Off” or “Off-scan,” and SAVE the changes to the channel.

Next, activate the ESC 8832 DAS by pressing any key on its laptop keypad. The main display screen for the ESC is shown in Figure 6. Verify that the “Digi-Trend Scheduler” program is running by looking for the red clock icon on the program tray. Click on “Stop Scheduler” to prevent the program from attempting to communicate through the serial port while it is being used for manual communications in “Link to Logger.”

At the main menu, type the operator’s initials in the “User Name” box. No Password is required. Click on the “ESC” logo. Select “OK”, select version 540S, go to the Utilities screen, and select “Link to Logger.” Log in by entering the letter “L” and then enter the password, “EPA”. Within the configuration menu (“C”), select “Disable/Mark Channel Offline” (“M”), and toggle the appropriate data channel with the space bar, thus turning the instrument to “disabled” to prevent invalid data from being recorded as valid.

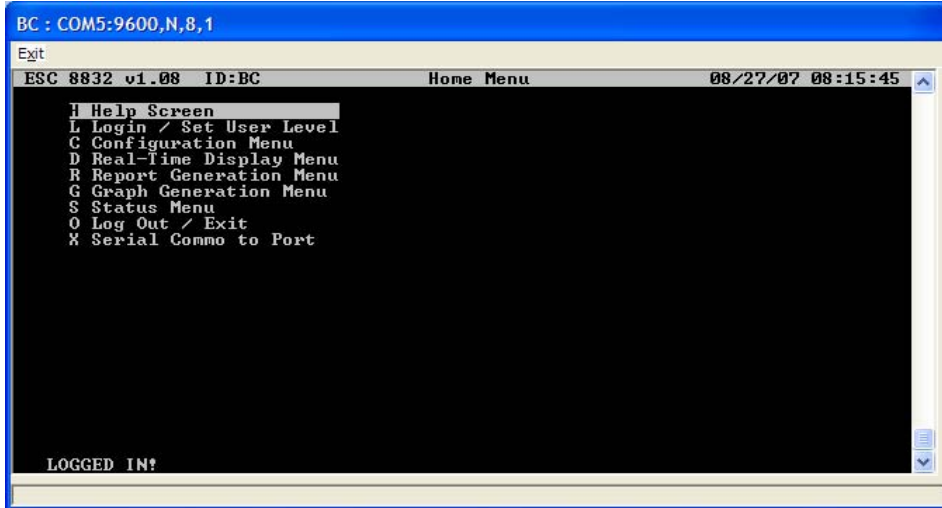


Figure 6. ESC 8832 Main Menu Display

Finally, turn the ambient air solenoid to the CO analyzer to the “closed” position to provide calibration air to the analyzer. To do this, go to the “Setup” of the EFW, select:

- Xview,
- Xdynamic data,
- Xinput/output, and then
- Xclick the circle corresponding to the CO analyzer and listen for the sound of the solenoid switching (circle changes from clear to red).

#### 7.4 Calibration System

The dynamic calibration system used at the Burdens Creek site is an Envirionics® Series 9100. The instrument can be programmed to automatically perform a zero, span, and precision check, and multipoint calibrations of ambient analyzers. Programming is executed using the pushbuttons located on the front panel. The front panel also has a backlit 25 line by 80 character liquid crystal display. To conduct an unadjusted, 3-point calibration, set the calibrator so that it produces only zero air:

- Xaccess the concentration mode on the calibrator by pushing the “F1” button,
- Xadjust the CO concentration to read 0.0,
- Xpush “F1” again.

The CO analyzer is now sampling zero air. Observe the display on the calibrator and the responses of the data acquisition systems until stable readings are shown for each instrument. For this zero air response, record all of the information requested in the



quality control results section of the data form used to record the diagnostic information (Figure 4). If the responses are out of limits, refer to the trouble shooting section of the operator's manual for the CO analyzer.

On the Environics® calibrator, adjust the CO concentration to 90% of full-scale, wait for stable readings from the calibrator and each DAS. Record the values observed for the stable readings from each device on the data form.

Set a new concentration on the calibrator for a precision check (250-500 ppb). Record the values once stable readings are displayed on the instruments. Set the concentration back to zero and observe the responses shown on the DASs. The instrument zero response (baseline) can optionally be adjusted at this time using the procedure specified in section 6.5.2.

If an unadjusted three point calibration (zero, span, precision) is being conducted, no further actions are necessary except for scheduled maintenance actions such as changing the particulate filter.

If an adjusted multipoint calibration is being performed, complete all the points specified on the data form and calculate a linear regression. Observe that each variable of the regression is within the specified limits; where for the slope (M),  $0.9800 < M < 1.0200$ , for the intercept (B),  $-40.00 < B < 40.00$  and  $R^2 > 0.9950$ . If the regression criteria are not met, determine a plan for troubleshooting the calibration system, the analyzer, and/or the data acquisition systems. Repeat the multipoint calibration and use the instrument controls to adjust the 48C-TLE response to zero and span concentrations (sections 6.5.2 and 6.5.3) before completing the remainder of the specified points.

## **7.5 Return Systems to Monitoring Mode**

Turn the ambient air solenoid to the CO analyzer to the “open” position to re-connect the analyzer to the ambient air stream. To do this, go to “setup” of the EFW, select:

Xview,

Xdynamic data,

Xinput/output, and then

Xclick the circle corresponding to the CO analyzer and listen for the sound of the solenoid switching (circle changes from red to clear).

For the EFW DAS, turn the solenoid off and then put the “STATE” to “On” from “Off-scan” for the appropriate channel. Finally, stop the Environics calibrator and set it to “READY” mode.

For the ESC 8832 DAS, within the configuration menu (“C”), select Enable/Mark Channel Online (“E”), and toggle the appropriate data channel with the space bar, thus turning the instrument to “enabled” to commence the collection of ambient. Use the <Esc> key to back out of the 8832 menu and logoff from the unit with the “O” menu choice. Exit from the E-DAS menu program and restart the Scheduler program.

## **7.6 Other Maintenance Checks**

In accordance with the biweekly schedule, change the particle filter on the CO analyzer(s). When finished, allow the instrument(s) to sample zero air and return to stable readings. Finally, set all instrument back to on-line conditions (i.e., sampling ambient air). See Section 9 of this SOP for a discussion of preventive maintenance activities.

## **7.7 Operational Requirements—Exiting the Station**

As a final check before leaving the station, review the operational requirements posted on the door. Make sure that the following conditions are in place:

- XEnvironics calibrator is in “Ready Mode”
- XManifold solenoid is turned off
- XEFW DAS channel STATE is on
- XESC DAS channel is enabled
- XNormalcy of EFW readings are verified

## **8.0 Quality Indicators**

Quality control for continuous electronic instruments, such as the TEI 48C TLE CO analyzer consists of performing the diagnostic checks, maintenance and calibrations as discussed earlier in this document. In Section 6, Figure 4 presented an example of a data form for recording QC and maintenance information that was developed by the EPA for the 48C TLE. In addition, information in Table 1, which shows the recommended operation parameters for the 48C TLE, should be reviewed. The operating parameters include recommended operating range, calibration ranges, and recommended cylinder concentrations. The following sections note the criteria for the quality indicators, precision, bias, representativeness, completeness, and comparability for monitoring CO at the Burdens Creek.

### **8.1 Precision Evaluation**

Precision is defined as the measure of agreement among individual measurements of the same property taken under the same conditions. For CO, this refers to testing the 48C TLE at concentrations between 0.250 and 0.500 ppm (250 and 500 ppb). The test must be performed, at a minimum, once every two weeks. The measured precision point

must agree with the expected value within  $\pm 15\%$ . The Burdens Creek site data set will be assumed to have met the DQO if the measurement quality objective (MQO) of 15% or better for precision is consistently met over the months and years of site operation.

## **8.2 Bias Evaluation**

Bias is defined as the degree of agreement between a measured value and the true, expected, or accepted value. For CO, this refers to testing the 48C TLE at various concentrations between the level of the precision point and more upscale calibration concentrations. The test must be performed, at a minimum, once every two weeks. The Burdens Creek site data set will be assumed to have met the DQO if the measurement quality objective (MQO) of 10% or better for bias is consistently met over the months and years of site operation.

## **8.3 Representativeness**

Representativeness refers to whether the data collected accurately reflect the conditions being measured. It is the data quality indicator most difficult to quantify. Unless the samples are truly representative, the other indicators are meaningless. Since the NCore siting criteria are generally intended to represent neighborhood, urban, or regional scales, the CO trace level criteria are the same. The National Monitoring Strategy, available on the AMTIC web site, discusses representativeness aspects of NCore monitoring sites.

## **8.4 Completeness**

Completeness is defined as the amount of data collected compared to a pre-specified target amount. For CO, EPA requires a minimum completeness of 75% (40 CFR 50, App. H.3) with a goal of 90%. Typical completeness of data capture by the TEI 48C TLE CO analyzer should exceed 90%.

## **8.5 Comparability**

Comparability is defined as the process of collecting data under conditions that are consistent with those used for other data sets of the same pollutant. The TEI 48C TLE meets the MQOs for a trace level CO instrument.

## **8.6 Method Detection Limits**

The method detection limit (MDL) or detectability refers to the lowest concentration of a substance that can be determined by a given procedure. The TEI 48C TLE analyzer must be able to detect a minimum value of 0.040 ppm of CO.

## **8.7 Measurement Quality Objectives**

Table 2 is a tabular presentation of the measurement quality objectives (MQOs) for CO set for the Burdens Creek site.

**Table 2. Measurement Quality Objectives for Carbon Monoxide: Burdens Creek Site**

Parameter	Criteria	Acceptable Range	Minimum Frequency (required/recommended)	Reference/Comment
<b>Critical</b>				
Precision (single analyzer)	250-500 ppb	Percent difference: $\pm 10\%$		
Zero/span check-level 1		Zero drift: 20 ppb Span drift: 10%	Daily	
<b>Operational</b>				
Shelter temperature		20 to 30 °C (hourly average) or operate instrument according to manufacturer's specifications		40 CFR Part 53.20
Temperature control		$\leq \pm 3^\circ\text{C}$ over 24 hours	Daily (hourly values)	digital temperature recording recommended
Precision and bias (Site Level)		Precision : 95% CI < 10% Absolute bias estimate: $\pm 10\%$		
Independent audit		Mean absolute difference $\leq 10\%$		
Federal audit (NPAP)	Mean concentration level	Mean absolute difference $\leq 10\%$	Once per year at selected sites	
Calibration (GPT capable)	Multipoint calibration (at least 4 points including zero)	Slope: $1.00 \pm 0.02$ , Intercept: $\pm 40$ ppb, $R^2: 0.995$	Upon receipt, after repair or adjustment, or once per 6 months	
Zero air		< 40 ppb	Annual zero air purity check	Check zero air generator against an independent standard
Gaseous standards	NIST Traceable 200-300 ppm	$\pm 1\%$		
Gaseous Dilution Systems (mass flow controller)	0-20 L/min for zero air 0-100cc/min gas flow	Accuracy $\pm 1\%$ (NIST traceable) Linearity: $\pm 1\%$ Precision: $\pm 1\%$	Once per 6 months	Verify air and gas flows with a NIST traceable primary or secondary standard. If a secondary standard is used, it must be certified against a NIST primary standard annually.
Detection	Noise	20 ppb (root mean square)	Once per year	
	Lower detectable level	40 ppb	Once per year	
	Method detection limit	18 ppb	Once per year	

Parameter	Criteria	Acceptable Range	Minimum Frequency (required/recommended)	Reference/Comment
<b>Systematic</b>				
Standard reporting units		ppb (final units in AQS)	All data	
Data reported (AQS)		Hourly		
Data stored (local)/averaging interval		5 minute values		
Completeness	Annually	75% of daily values		
	Daily	75% of hourly values		
	Hourly	75% of hour		
Sample path residence times		<20 seconds	Continually	40 CFR Part 58, Appendix E
Sample probe material		Borosilicate glass, FEP & PTFE (Teflon)	Continually	40 CFR Part 58, Appendix E
Siting		Per 40 CFR Part 58, Appendices D and E	Continually	40 CFR Part 58, Appendices D and E
Equipment		Reference or Equivalent Method (if used for NAAQS determinations)		

### 9.3 Performance Evaluation Audits

A performance evaluation (PE) is a quantitative comparison of results between the Burdens Creek equipment and an independent audit system brought to the site. The audit system produces gas concentrations that are assayed by the 48C TLE CO analyzer. The responses of the on-site analyzer are then compared against the calculated concentration from the independent audit system and a linear regression is generated.

The PE is conducted through the EPA Regional Office by means of participation in the National Performance Audit Program (NPAP). The Burdens Creek/Ambient Air Monitoring Group will participate in the NPAP on an annual basis. When NPAP audits are not available, performance evaluations will be performed through a cooperative agreement with the North Carolina Division of Air Quality, Raleigh, NC. An acceptable audit result requires that the average difference between the designated audit values and the site's CO analyzer be no greater than 7%.

Comment [CVW1]: Need input from EPA for agreement criteria for CO

Comment [SR2]: Isn't the criterion specified in the MQOs? As I read it, the value is 10%...

A through-the-probe audit may be a component of the PE. If so, known concentrations of CO will be introduced at the outside ambient air inlet of the station and will traverse the all tubing and the sampling manifold from which the 48C TLE analyzer samples.

### 9.4 Technical Systems Audits

A technical systems audit (TSA) is a thorough, systematic, on-site qualitative examination of facilities, equipment, training, technical procedures, record-keeping activities, data validation, data management, and reporting aspects of a monitoring station or system. Evaluation of the Burdens Creek site's CO measurement system is a component of monitoring site operations. Ideally, technical systems audits are conducted by the EPA Regional Office at least once every 3 years.

The OAQPS/AAMG also performs an annual internal technical systems audit of the site operations. For this type of assessment, the AAMG will use the technical systems audit forms found in Appendix 15 of the *Quality Assurance Handbook for Air Pollution Measurement Systems*, Volume II, Part 1.

### 9.5 Procedures in the Event of an Audit Failure

Comment [CVW3]: Need input from EPA

*Need input from EPA for this section.....*

### 10.0 Preventive Maintenance

Preventive maintenance should be a deterrent to down-time and data loss. Table 3 lists the preventive maintenance items that are should be performed. Please see section

5-1 of the owner's manual. Section 5-1 also has a list of the spare parts that the operator should keep in stock.

**Table 3. Preventive Maintenance Schedule for the TEI 48C TLE**

Event	Frequency
Replace particle filter	Biweekly
Diagnostics checks	Biweekly
Perform level 1 calibration	Daily
Replace IR source	As needed
Leak check and pump check out	Annually by contractor
Inspect pneumatic lines	Semi-annually
Clean inside of chassis	As needed
Rebuild or replace pump	As needed
Clean optic bench	As needed
Replace wheel motor	As needed
Replace gases in correlation wheel	As needed

### 10.1 Instrument Troubleshooting

The TEI 48C TLE manual has an excellent troubleshooting guide in Section 6-1 of the manual. For details on using the Test Functions for predicting failures, please reference this section.

### 11.0 References

1. Standard Operating Procedures. Thermo Electron Corporation Model 48C TLE Trace Level CO Instrument. Version 1.10, Final. March 17, 2005
2. Ambient Air Surveillance, Code of Federal Regulations. Title 40, Part 58.
3. Model 48C Trace Level Gas Filter Correlation CO Analyzer. Instruction Manual P/N 14023. THERMO Environmental Instruments Inc. 8 West Forge Parkway. Franklin, Massachusetts 02038.
4. Technical Assistance Document (TAD) for Precursor Gas Measurements in the NCore Multi-pollutant Monitoring Network. Version 4. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. Emissions, Monitoring, and Analysis Division. Research Triangle Park, North Carolina. 27711. EPA-454/R05-003. September 2005.